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OSIRIS-REx-RQMT-0001
Effective Date: October 2018
Revision L
Code 433

Origins Spectral Interpretation, Resource Identification, and Security-Regolith Explorer (OSIRIS-REx) Project

Mission Requirements Document

OSIRIS-REx-RQMT-0001

Revision L

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Goddard Space Flight Center
Greenbelt, Maryland

National Aeronautics and Space Administration

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CM FOREWORD

This document is an OSIRIS-REx Project controlled document. Changes to this document require prior approval of the OSIRIS-REx Project CCB Chairperson. Proposed changes shall be submitted to the OSIRIS-REx Project Configuration Management Office (CMO), along with supportive material justifying the proposed change.

In this document, a requirement is identified by “shall,” a good practice by “should,” permission by “may” or “can,” expectation by “will” and descriptive material by “is.”

Questions or comments concerning this document should be addressed to:

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OSIRIS-REx Project
Mission Requirements Document

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DOCUMENT CHANGE RECORD Sheet: 1 of 1

REV/ VERSION LEVEL	DESCRIPTION OF CHANGE	APPROVED BY	DATE APPROVED
Revision –	Initial Release of Baseline Approved by CCR-0014	CCR-0014	February 2012
Revision A	Release of Baseline Approved by CCR-0021	CCR-0021	May 2012
Revision B	Release of Baseline Approved by CCR-0048	CCR-0048	September 2012
Revision C	Release of Baseline Approved by CCR-0073	CCR-0073	April 2013
Revision D	Release of Baseline Approved by CCR-0115	CCR-0115	August 2013
Revision E	Release of Baseline Approved by CCR-0177	CCR-0177	February 2014
Revision F	Release of Baseline Approved by CCR-0299 (Numerous changes made including changes related to flight dynamics, radio science, and subsystem allocations.)	CCR-0299	October 10, 2014
Revsion G	Updated to reflect the "Higher Wet Mass At Launch" change	CCR-0332	October 14, 2014
Revsion H	Updated for TAG reduncancy, backup MSA, quick updates, and to correct flow down to the Ground Sysem.	CCR-0369	February 18, 2015
Revision I	CM Note: There is no release to this Revision	N/A	N/A
Revision J	Updated for shape model requirements. Also, note that a document format correction was made with the referencing (mis-numbering) of the "Object Numbers" starting in section 4.	CCR-0442	April 14, 2015
Revision K	Updated flight system performance during launch and AAM1. Added requirements to control the shape model product interface between the SPOC and NFT.	CCR-0618	March 11, 2016
Revision L	Added requirement for curation service and facility.	CCR-0754	October 10, 2018

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LIST OF TBDs/TBRs

ID	Reason for TBD/TBR	Due Date, Working Group

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1 INTRODUCTION

1.1 MISSION OVERVIEW

The Origins, Spectral Interpretation, Resource Identification, and Security–Regolith Explorer (OSIRIS-REx) mission will return the first pristine samples of carbonaceous material from the surface of a primitive asteroid. OSIRIS-REx's target asteroid Bennu is the most exciting, accessible volatile and organic-rich remnant from the early Solar System, as well as the most potentially hazardous asteroid known to humanity.

With launch in September 2016, OSIRIS-REx begins a three-year cruise to Bennu that includes an Earth Flyby / Gravity Assist in September of 2017. OSIRIS-REx first detects Bennu 60 days in advance of rendezvous, utilizing its slow approach to characterize the integrated properties of Bennu and survey its environment for natural satellites. OSIRIS-REx then spends the next 7 months characterizing the surface and orbital environment of Bennu, culminating with insertion into a 1km-radius "safe home"orbit from which all reconnaissance and sampling sorties are initiated. Four candidate sample sites are characterized with OSIRIS-REx's instrument suite, and each step in the Touch-And-Go (TAG) maneuver sequence is performed prior to attempting sample collection. In September 2020, OSIRIS-REx executes the TAG and collects both bulk and surface samples. After 5 months of quiescent ops, or additional sampling attempts if needed, OSIRIS-REx departs Bennu. Following a 2.5 year ballistic return cruise, the Sample Return Capsule is released, re-entering Earth's atmosphere and landing at the Utah Test & Training Range in September, 2023.

OSIRIS-REx is a Principal Investigator (PI)-led mission. The PI, Dante Lauretta, and his deputy, Ed Beshore, work for the University of Arizona (UA). They have delegated project management to Goddard Space Flight Center. GSFC also provides the systems engineering, technical authority, and safety and mission assurance for the project. Lockheed Martin in Littleton, CO is building the spacecraft, integrating the flight system, and operating it. KinetX's is providing the technical expertise for flight navigation, under the management of GSFC's flight dynamics organization.

Scientific Objectives of the OSIRIS-REx Asteroid Sample Return Mission are:

1. Return and analyze a sample of pristine carbonaceous asteroid regolith in an amount sufficient to study the nature, history and distribution of its constituent minerals and organic material.
2. Map the global properties, chemistry, and mineralogy of a primitive carbonaceous asteroid to characterize its geologic and dynamic history and provide context for the returned samples.
3. Document the texture, morphology, geochemistry, and spectral properties of the regolith at the sampling site in situ at scales down to the subcentimeter.
4. Measure the Yarkovsky effect on a potentially hazardous asteroid and constrain the asteroid properties that contribute to this effect.
5. Characterize the integrated global properties of a primitive carbonaceous asteroid to allow for direct comparison with ground-based telescopic data of the entire asteroid population.

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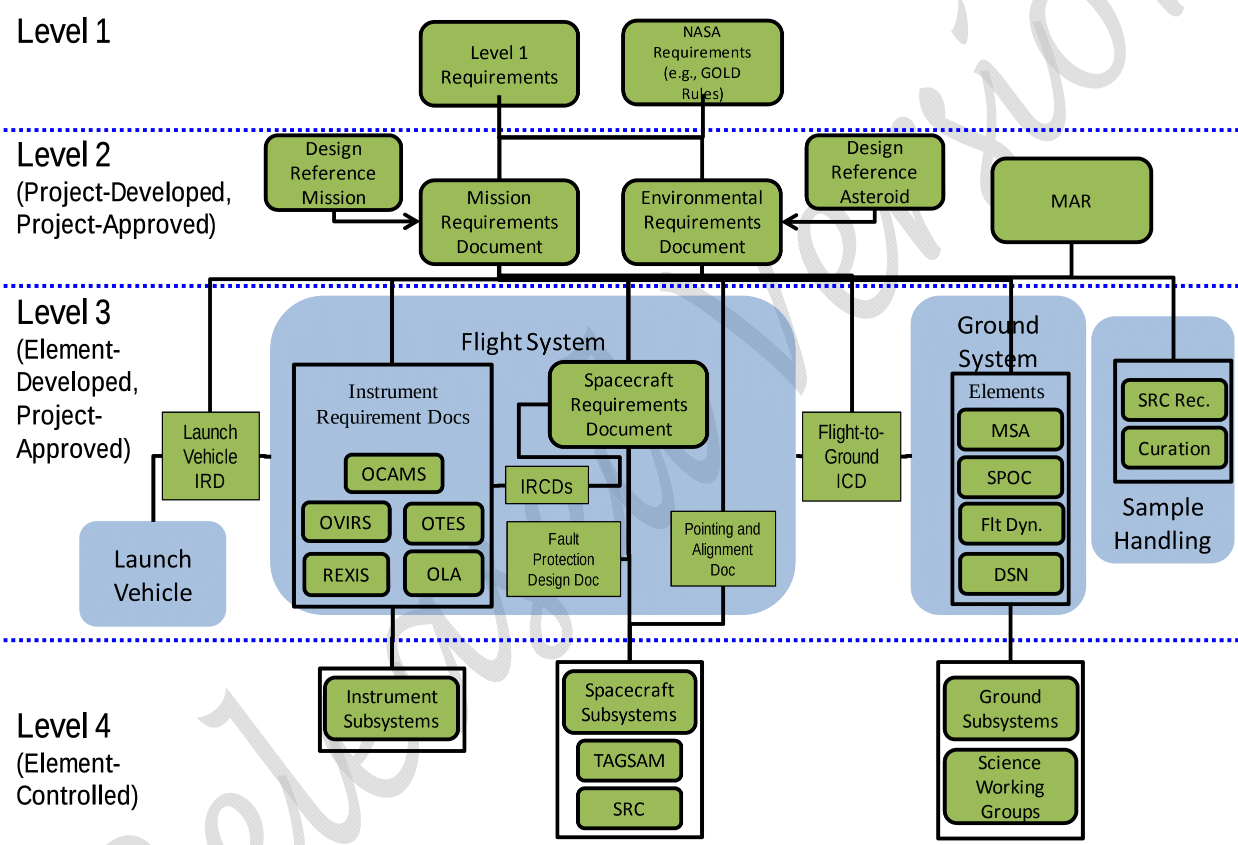
More details about the OSIRIS-REx mission are contained in the New Frontiers Concept Study Report dated January 28, 2011.

1.2 REQUIREMENTS FLOW DOWN

The OSIRIS-REx requirements flow down structure is shown in Figure 1-1. Level 1 Science requirements, as well as NASA institutional requirements, flow down to Level 2 in the MRD, ERD, and MAR. Rationales, traceability, and verification method attributes have been captured for each MRD requirement. From Level 2, requirements are flowed down to the spacecraft, and ICDs, payload instruments, and ground elements at Level 3, and the payload instruments and ground elements flight and ground subsystems at Level 4. Top level ground system requirements are captured in the MRD, so no Level 3 document is needed for this system.

Figure 1 -1 OSIRIS-REx requirements flow down structure



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2 APPLICABLE DOCUMENTS

2.1 NASA DOCUMENTS

NPR 8020.12	Planetary Protection Provisions for Robotic Extraterrestrial Missions
NPR 8705.4	Risk Classification for NASA Payloads
NPR 8715.5	Range Flight Safety Program
NASA-STD-8719.14	Process for Limiting Orbital Debris
GPR 8070.4	Administration and Application of Goddard Rules for Design, Development, Verification and Operation of Flight Systems
GSFC-STD-1000	Rules for Design, Development, Verification and Operation of Flight Systems

2.2 OSIRIS-REX PROJECT DOCUMENTS

OSIRIS-REx-RQMT-0002	OSIRIS-REx Environmental Requirements Document
OSIRIS-REx-OPS-0001	OSIRIS-REx Design Reference Mission
OSIRIS-REx-PLAN-0011	OSIRIS-REx Contamination Control Plan
NWFR-PLAN-001	Appendix F to the New Frontiers Program Plan: Program Level Requirements for the OSIRIS-REx Project
OSIRIS-REx-ICD-0007	OSIRIS-REx Spacecraft – to – Launch Vehicle Interface Control Document
OSIRIS-REx-ICD-0001	OCAMS – to – OSIRIS-REx Spacecraft Interface Requirements and Control Document
OSIRIS-REx-ICD-0002	OVIRS – to – OSIRIS-REx Spacecraft Interface Requirements and Control Document
OSIRIS-REx-ICD-0003	OTES – to – OSIRIS-REx Spacecraft Interface Requirements and Control Document
OSIRIS-REx-ICD-0004	OLA – to – OSIRIS-REx Spacecraft Interface Requirements and Control Document
OSIRIS-REx-ICD-0005	REXIS – to – OSIRIS-REx Spacecraft Interface Requirements and Control Document
NFP3-PN-12-OPS-9 (LM deliverable)	OSIRIS-REx Flight – to – Ground Interface Control Document
NFP3-PN-12-OPS-6A (LM deliverable)	Mission Support Area – to – Science Processing and Operations Center Interface Control Document
NFP3-PN-12-OPS-6C (LM deliverable)	Mission Support Area – to – Flight Dynamics System Interface Control Document
UA-ICD-9.0.0-100 (SPOC deliverable)	Science Processing and Operations Center – to – Flight Dynamics System Interface Control Document
OSIRIS-REx-ICD-0008	OSIRIS-REx Ground System – to – DSN Interface Control Document

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ID	Object Number	PLA-OSIRIS-REx-RQMT-0001, Rev K, Released by CCR-0618, Dated March 11, 2016	Rationale	Subsystem Allocation	Parent ID
MRD-431	1	Introduction Please visit the OSIRIS-REx MIS at https://ehpdmis.gsfc.nasa.gov and view the full version of this document (OSIRIS-REx-RQMT-0001) to see this section.			
MRD-432	2	Applicable Documents Please visit the OSIRIS-REx MIS at https://ehpdmis.gsfc.nasa.gov and view the full version of this document (OSIRIS-REx-RQMT-0001) to see this section.			
MRD-348	3	Science Requirements			
MRD-654		NOTE: Values for spatial resolution when applied to optical imaging are assumed to be over 3 pixels unless otherwise specified.			
MRD-349	3.1	Sample Return & Analysis Requirements			
MRD-259	3.1.1	OSIRIS-REx Science Sample Mass			
MRD-105		OSIRIS-REx shall return > 15 g of bulk material for analysis in support of mission science objectives.	Amount of returned sample required to achieve mission science objectives.	Mission System, Curation	PLRA31 PLRA50
MRD-260	3.1.2	NASA Sample Mass			
MRD-106		OSIRIS-REx shall return > 45 g of bulk material in support of NASA objectives.	NASA requirement not to consume more than 25% of returned sample.	Mission System, Curation	PLRA31 PLRA50
MRD-261	3.1.3	Total Elemental Contamination			
MRD-107		OSIRIS-REx shall limit the contamination on the TAGSAM Sampler Head, TAGSAM launch container interior, and SRC canister interior to levels at or below those specified by IEST-STD-CC1246 level 100 A/2 until launch for TAGSAM and fairing door closure for the SRC.	IEST-STD-CC1246 level 100 A/2 provides for total inorganic contamination levels of key elements that satisfy the project definition of 'pristine' that no foreign material introduced into the sample hampers the scientific analysis of the sample. This requirement applies to the SRC until fairing door closure because it has a pull on purge line as the build-to-print SRC release mechanism is not designed to have a T0 purge line. With positive pressure until SRC purge line removal, the requirement for contamination control can be verified. After purge line removal, contaminants should stay out of the SRC due to the high pressure drop due to the SRC filter; however, this is not currently verifiable.	Spacecraft	PLRA31
MRD-262	3.1.4	Hydrazine Contamination			
MRD-108		OSIRIS-REx shall limit total hydrazine contamination on the TAGSAM Head surface to <180 ng/cm2.	Total allowable hydrazine contamination equal to total amino acid contamination allowed by mission guidelines.	Spacecraft	PLRA31
MRD-263	3.1.5	Amino Acid Contamination			

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MRD-109		OSIRIS-REx shall limit exposure of the bulk sample to total amino acid contamination < 180 ng/cm2 on the TAGSAM Head surface.	Stardust contamination control successfully achieived mission science objectives. Stardust worst case is 180 ng/cm2 amino acid contamination.	Spacecraft	PLRA31
MRD-264	3.1.6	Contamination Documentation of the TAGSAM Head			
MRD-110		OSIRIS-REx shall document the contamination acquired by the TAGSAM Sampler Head during assembly and flight.	Ensure a chain of evidence, linking the acquired sample with its contamination experience.	Flight System, Spacecraft, MSA, Curation	PLRA32 PLRA51
MRD-265	3.1.7	Contamination Control Plan			
MRD-111		OSIRIS-REx shall generate and follow the project contamination control plan.	Needed to ensure cleanliness of the flight system, UTTR SRC receiving facility, and the curation facility, with corresponding documentation. Details of the project contamination control and documentation procedures are best described in a detailed plan.	Spacecraft, OCAMS, OTES, OVIRS, OLA, REXIS, SRC Recovery, Curation	PLRA32 PLRA51 PLRA100
MRD-266	3.1.8	TAGSAM Contact Surface Area For OSIRIS-REx Science			
MRD-112		OSIRIS-REx shall contact with the surface of Bennu and return > 6.5 cm2 of the surface-contact pad in support of mission science objectives	Backup sample collection technique in case primary bulk sample acquisition is unsuccessful.	Mission System, Curation	PLRA33 PLRA52
MRD-267	3.1.9	TAGSAM Contact Surface Area for NASA			
MRD-113		OSIRIS-REx shall contact with the surface of Bennu and return > 19.5 cm2 of the surface-contact pad in support of NASA objectives	NASA requirement not to consume more than 25% of returned sample.	Mission System, Curation	PLRA33 PLRA52
MRD-277	3.1.10	Estimation of Collected Surface Sample			
MRD-190		OSIRIS-REx shall estimate the area of surface sample collected by the TAGSAM Sampler Head surface-contact pads.	Estimate of amount of surface sample collected allows for indirect assessment of sampling success	Mission System, SPOC	PLRA33 PLRA52
MRD-350	3.2	Sample Site Texture, Morphology, Geochemistry & Spectral Properties Documentation Requirements			
MRD-268	3.2.1	Sample Site Identification			
MRD-114		OSIRIS-REx shall analyze the surface of Bennu to identify at least one potential sample site of scientific value.	Any collected sample must be acceptable to the PI.	Ground System, SPOC	PLRA34 PLRA53
MRD-269	3.2.2	Sample Site Topographic Maps			
MRD-115		OSIRIS-REx shall, for a 3-sigma TAG delivery error ellipse around each of up to 12 candidate sampling sites, produce a topographic map at < 5cm spatial resolution and < 5cm (1-sigma) vertical precision.	5-cm resolution over a 3-sigma TAG error ellipse is needed to assess safety and sampleability of candidate sites. It is expected that maps produced from OCAMS data collected during Orbital B and OLA data collected during Recon will provide this resolution.	Mission System, OCAMS, SPOC	PLRA34 PLRA53 MRD-574

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MRD-281	3.2.3	Sample Site Particle Size-Frequency Distribution			
MRD-116		OSIRIS-REx shall, for > 80% of a 2-sigma TAG delivery error ellipse around at least 2 candidate sampling sites map the areal distribution and determine the particle size-frequency distribution of regolith grains < 2-cm in longest dimension.	Required to assess if the particle size-frequency distribution is compatible with TAGSAM capabilities.	Mission System, OCAMS, SPOC	PLRA34 PLRA53 MRD-80
MRD-283	3.2.4	Sample Site Minerals and Organics Maps			
MRD-118		OSIRIS-REx shall, for > 40% of a 2-sigma TAG delivery error ellipse around at least the prime sampling site, map the distribution of key species listed in the MRD-118 Table (Absorption Features of Key Mineralogical & Organic Molecules) that have spectral features with > 5% absorption depth at a spatial resolution < 5m.	5-m resolution provides enough information to evaluate the spectral diversity of the sample ellipse; key minerals and organics determined by comparison to carbonaceous chondrites.	Mission System, Pointing, OVIRS, OTES, SPOC	PLRA34

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MRD-530	**MRD-118 Table**				

Absorption Features of Key Mineralogical & Organic Molecules

Material	Selected Modes	Band Center (µm)	Band Width (µm)	Instrument
H_2O adsorbed on grains	O-H stretch	2.95	0.28	OVIRS
	H-O-H bend	6.15	0.2	OTES
Phyllosilicates	O-H stretch from structural OH	2.74	0.03	OVIRS
Carbonates	Internal and lattice vibrations	>1.6	variable	OVIRS
	C-O stretch	6.3 - 6.7	0.9	OTES
	C-O bend	11.1 - 11.4 13.3 - 14.0 27.0 - 31.0	0.7 0.4 9 - 17	OTES
Sulfates	Ferric pigment	0.4 - 0.6	0.2	OVIRS
	Fe^{3+} electronic absorptions	0.44, 0.95	0.02, 0.40	OVIRS
	Combination & overtones of H_2O and metal-OH fundamental vibrational modes	1.48 - 2.21	variable	OVIRS
	S-O stretches	8 - 12	1.0 - 2.5	OTES
	S-O bends	14 - 25	variable	OTES
	Lattice vibrations (incl. metal - O)	>18 - 20	variable	OTES
Silicates	Electronic transitions (e.g., Fe^{2+} and Fe^{3+} in pyroxene and olivine)	~1.0 and 2.0	0.3 - 0.5, 1.0	OVIRS
	Si-O stretches	8 - 12	variable	OTES
	Si-O bends	15 - 20	variable	OTES
	Chain and lattice modes	>15	variable	OTES
Oxides	Fe^{3+} electronic transitions	0.35 - 1.00	0.02 - 0.4	OVIRS
	Metal-O fundamental vibrations	>12.5	variable	OTES
PAHs	Aromatic C-H stretch	3.29	0.03	OVIRS
Aliphatic hydrocarbons	$-CH_3$-groups, asymmetric C-H stretch	3.38	0.02	OVIRS
	$-CH_3$-groups, asymmetric C-H stretch	3.42	0.02	OVIRS
	$-CH_3$-groups, asymmetric C-H stretch	3.48	0.01	OVIRS
	$-CH_3$-groups, asymmetric C-H stretch	3.50	0.01	OVIRS

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MRD-284	3.2.5	3.2.5 Sample Site Color Maps			
MRD-119		OSIRIS-REx shall, for > 80% of a 2-sigma TAG delivery error ellipse around at least the prime sampling site, map the surface in a panchromatic filter at <25 cm resolution and map the ECAS b-v color index, v-x color index, and the relative depth of the 0.7-micron absorption feature, relative to one or more recognized ECAS standard stars, with an accuracy of < 2% in regions where the signal-to-noise ratio is >100 at a spatial resolution < 50 cm.	These photometric properties provide basic information about the chemistry, mineralogy, and diversity of the sampling sites.	Mission System, OCAMS, SPOC	PLRA34
MRD-379	3.2.6	Documentation of Sample Collection Event			
MRD-380		OSIRIS-REx shall image the sample collection event.	Documentation required to determine context of the acquired sample and assist in verification of sampling success.	Mission System, SPOC	PLRA34
MRD-539	3.2.7	Sample Site Thermal Inertia Maps			
MRD-540		OSIRIS-REx shall, for > 80% of a 2-sigma TAG delivery error ellipse around each of up to 12 candidate sampling sites, measure the absolute flux of thermally emitted radiation with 3% accuracy and use it to derive and map thermal inertia at a spatial resolution <8m.	8m resolution provides enough information to evaluate the diversity of the sample ellipse; 3% accuracy provides information on average grain size and regolith depth.	Mission System, OTES, SPOC	PLRA34
MRD-607	3.2.8	Sample Site Tilt Maps			
MRD-608		OSIRIS-REx shall, for a 3-sigma TAG delivery error ellipse around each of up to 12 candidate sampling sites, produce a tilt-distribution map accurate to +/-7° (1-sigma) in tilt, relative to the sampling plane, and spatial resolution < 32cm. The sampling plane is the plane normal to which the spacecraft negative Z-axis is commanded for TAG, defined by the 2σ TAG delivery error ellipse average normal vector.	Needed to assess the safety and sampleability of candidate sites. Surface tilt impacts both TAG contact dynamics and sample collection efficiency. This means that tilts > 7° will be considered unacceptable for TAG. It is expected that maps produced from OCAMS data collected during Orbital B and OLA data collected during Recon will provide this resolution.	Mission System, OCAMS, SPOC	PLRA34 PLRA53 MRD-40 MRD-573
MRD-285	3.2.9	Sample Allocation and Analysis Plan			
MRD-120		OSIRIS-REx shall generate and follow a project sample allocation and analysis plan to address the science objectives including those in PLRA 37.	A detailed plan is needed to maximize the science return from the collected sample and incorporate advances in analytical capabilities.	Curation	PLRA37 PLRA56
MRD-609	3.2.10	Sample Catalog			
MRD-610		OSIRIS-REx shall produce a sample catalog within 6 months of Earth return of the Sample Return Capsule.	6 months is sufficient to catalog the returned sample with enough detail to allow the broader scientific community to intelligently request samples for analysis. (Verbatim from PLRA).	Curation	PLRA36 PLRA55

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	3.2.11	Curation Service & Facility			
MRD-735		OSIRIS-REx shall implement a curation service and facility capable of • Receiving the SRC and returned asteroid sample from LM and storing them under controlled conditions; • Documenting the received SRC and asteroid sample to enable Science Team preliminary examination, catalog production, and sample analysis; • Supporting the Science Team during SRC and sample preliminary examination and catalog production, which will be complete within six months after the transfer of samples from LM to NASA/JSC; • Selecting and distributing representative sample splits to the CSA, JAXA, and the NASA White Sands facility, per the relevant interagency agreements and NASA policy; • Supporting the Science Team during SRC and sample analysis, which shall be complete by September 30, 2025; • Ensuring a seamless transfer of curation responsibility from the OSIRIS-REx PI to NASA on October 1, 2025; • Maintaining the pristine nature of the sample for a period of not less than fifty years, and • Fulfilling CAPTEM-approved sample requests for a period of not less than fifty years to enable long-term science	This requirement captures three gaps in the current level 2 requirements (no mention of cleanroom, no mention of international MOUs, and recognition of need to integrate mission and long-term goals), and permits the development of corresponding level 3 requirements.	Curation	PLRA36 PLRA37 PLRA55 PLRA56

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MRD-351	3.3	Bennu Global Properties, Chemistry & Minerology Mapping Requirements			
MRD-286	3.3.1	Global Imaging of Bennu			
MRD-121		OSIRIS-REx shall image > 80% of the surface of Bennu with < 21cm spatial resolution (4-pixel criterion) to produce a global mosaic, stereo images, mosaics of hazards and regions of interest, and image sequences of the asteroid surface.	21cm spatial resolution sufficient to characterize the sampleability and safety of > 80% of the surface of Bennu and identify up to 12 candidate sites for more detailed reconnaissance. Science requires 1m spatial resolution.	Mission System, Pointing, OCAMS, Ground System, SPOC, Spacecraft	PLRA38 PLRA57 MRD-122 MRD-126 MRD-611
MRD-287	3.3.2	Global Topography of Bennu			
MRD-122		OSIRIS-REx shall, for > 80% of the asteroid surface, produce a topographic map at spatial and vertical resolution < 1m.	1-m spatial and vertical resolution sufficient to characterize the sampleability and safety of potential sampling sites.	Mission System, OLA, SPOC, OCAMS	PLRA38 PLRA57
MRD-288	3.3.3	Bennu Shape Model			
MRD-123		OSIRIS-REx shall produce a > 1 million vector shape model.	1 million vectors provides ~1 m2 tiles on shape model.	Pointing, SPOC	PLRA38 PLRA57
MRD-289	3.3.4	Shape Model Center Of Figure			
MRD-124		OSIRIS-REx shall determine the shape model center of figure to within 1-m.	Center of figure needed to define coordinate system, 1-m consistent with shape model resolution. Center of figure required to determine density heterogeneity.	SPOC	PLRA38 PLRA57 MRD-123
MRD-290	3.3.5	Bennu Coordinate System			
MRD-125		OSIRIS-REx shall designate a prime meridian using a distinctive surface feature and define the coordinate system for Bennu.	Prime meridian needed to define coordinate system. Coordinate system needed for co-registration of all data products.	SPOC	PLRA38 PLRA57
MRD-291	3.3.6	Global Distribution of Surface Slopes			
MRD-126		OSIRIS-REx shall, for > 80% of the asteroid surface, produce a slope-distribution map with a precision of +/- 7.5° in slope, relative to the geoid surface, and spatial resolution < 1m.	Surface slopes needed to identify regions of significant regolith pooling. Slopes of <15 degrees are required for safety and sampleability and are consistent with a relaxed surface where regolith has accumulated.	Mission System, OLA, OCAMS, SPOC	PLRA39 PLRA58
MRD-292	3.3.7	Rotation Pole			
MRD-127		OSIRIS-REx shall determine the rotation pole (right ascension, declination, and obliquity) of Bennu relative to J2000 to within 1° in each parameter.	Rotation pole location needed to define coordinate system, pole orientation critical to determine surface acceleration distribution. One degree is equivalent to tracking the rotation pole in the body-fixed frame to the order of a few meters.	SPOC	PLRA39 PLRA46 PLRA58
MRD-293	3.3.8	Wobble of Rotation Pole			

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MRD-128		OSIRIS-REx shall determine the amount of wobble in the rotation pole of Bennu to within 1°.	Pole wobble needed to understand any recent perturbation to the asteroid's spin state. This level of precision will enable estimation of the moments of inertia of the body should the asteroid be in a clearly detectable excited rotation state.	SPOC	PLRA39 PLRA58
MRD-294	3.3.9	Rotation Period			
MRD-129		OSIRIS-REx shall measure the rotation period of Bennu to within 10 seconds.	Rotation period needed to define coordinate system, surface velocity distribution and surface accelerations. 10s in time is on the order of 1m of surface motion.	SPOC	PLRA39 PLRA58
MRD-295	3.3.10	Surface Gravity Field			
MRD-130		OSIRIS-REx shall, for > 80% of the asteroid surface, map the surface gravity field to within 5x10-6 m/s2 at spatial resolution < 1m	Gravity field variations are a key contributor to total surface accelerations, precision is consistent with total mass uncertainty of the asteroid.	SPOC	PLRA39 PLRA58
MRD-296	3.3.11	Roche Lobe			
MRD-131		OSIRIS-REx shall compute the Roche lobe of Bennu with < 1m spatial resolution.	Roche lobe is an iso-energy surface that surrounds the asteroid and separates it from the rest of the Solar System. If a particle close to the asteroid has less than this energy, then it is impossible for it to escape from the asteroid.	SPOC	PLRA39PLRA58
MRD-274	3.3.12	YORP Effect			
MRD-193		OSIRIS-REx shall determine the YORP effect on Bennu to a precision of < 1.0E-3 degrees/day/year.	The YORP effect can significantly alter the rotation state of small asteroids. Knowledge of this effect is important for constraining the dynamical history of the asteroid. The stated precision is 20% of the predicted value for the YORP effect on this asteroid.	SPOC	PLRA39 PLRA58
MRD-297	3.3.13	Bennu Volume			
MRD-132		OSIRIS-REx shall determine the volume of Bennu to within 0.9%.	Volume needed to determine the density. 0.9% error on volume (and 0.5% of mass) provides 1% error on density.	SPOC, Pointing	PLRA40 PLRA59
MRD-298	3.3.14	Bennu Mass			
MRD-133		OSIRIS-REx shall determine the mass of Bennu to within 0.5%.	Mass needed to determine the density. 0.5% error on mass (and 0.9% on volume) provides 1% error on density.	SPOC	PLRA40 PLRA46 PLRA59
MRD-299	3.3.15	Gravity Field Spherical Harmonic Coefficients			
MRD-134		OSIRIS-REx shall determine the spherical harmonic coefficients of Bennu's gravity field to fourth degree and order.	A fourth-degree-order field provides sufficient data for detecting macroscopic internal density variations, higher precision may be limited by solar radiation pressure perturbations.	Mission System, SPOC	PLRA40 PLRA59
MRD-300	3.3.16	Bennu Center Of Mass			

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MRD-135		OSIRIS-REx shall determine the center of mass of Bennu to within 1-m.	Center of mass, combined with center of figure, provides estimate of density heterogeneity. Center of mass provides the baseline reference for topography measurements.	SPOC	PLRA40 PLRA59
MRD-273	3.3.17	Bennu Density			
MRD-194		OSIRIS-REx shall determine the density of Bennu to within 1% and constrain the density distribution.	Calculation of asteroid density allows comparison to known meteorites and constrains internal structure.	SPOC	PLRA40 PLRA41 PLRA59
MRD-301	3.3.18	Crater Distribution			
MRD-136		OSIRIS-REx shall identify and map the distribution of all craters on > 80% of the surface of Bennu > 5-m in diameter.	1-m resolution provides enough information to definitively identify circular features likely to be craters >5-m across.	SPOC	PLRA41
MRD-302	3.3.19	> 21 cm Boulder Distribution			
MRD-137		OSIRIS-REx shall identify and map the distribution of all boulders on > 80% of the surface of Bennu >21cm in longest dimension.	A rock > 21cm in size could block the TAGSAM collection inlet. 21cm over 4-pixel resolution permits identification of features likely to be rocks > 21cm, to be confirmed with 5cm resolution imaging for up to 12 candidate sample sites.	SPOC	PLRA41 MRD-611
MRD-303	3.3.20	Regolith Distribution			
MRD-138		OSIRIS-REx shall identify and map the distribution of all regions on > 80% of the surface of Bennu > 1-m in shortest dimension where regolith is present.	1-m resolution provides enough information to definitively identify irregular features that are areas of regolith accumulation.	SPOC	PLRA41 PLRA60
MRD-304	3.3.21	Linear Feature Distribution			
MRD-139		OSIRIS-REx shall identify and map the distribution of all linear features on > 80% of the surface of Bennu > 1-m in width and > 10-m in length.	1-m resolution provides enough information to definitively identify linear features >1-m across; 10:1 aspect ratio sufficient to characterize a feature as linear. Linear features provide information about surface expression of interior structure.	SPOC	PLRA41
MRD-272	3.3.22	Geologic Properties Analysis			
MRD-195		OSIRIS-REx shall analyze the geologic properties of the asteroid to constrain its geologic and dynamic history.	The geologic and dynamic history are critical to providing full context of the returned sample.	SPOC	PLRA41
MRD-305	3.3.23	Global Spectral Mapping			
MRD-140		OSIRIS-REx shall, for > 80% of the asteroid surface, map those spectral features listed in MRD-140 Table (Absorption Features of Key Mineralogical & Organic Molecules) with > 5% absorption depth at < 50m spatial resolution.	50-m resolution provides enough information to identify spectrally interesting regions on the scale of the sample ellipse; key minerals and organics determined by comparision to carbonaceous chondrites.	Mission System, Pointing, OVIRS, OTES, SPOC	PLRA42

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MRD-531		**MRD-140 Table** (table below)			

Absorption Features of Key Mineralogical & Organic Molecules

Material	Selected Modes	Band Center (µm)	Band Width (µm)	Instrument
H_2O adsorbed on grains	O-H stretch	2.95	0.28	OVIRS
	H-O-H bend	6.15	0.2	OTES
Phyllosilicates	O-H stretch from structural OH	2.74	0.03	OVIRS
Carbonates	Internal and lattice vibrations	>1.6	variable	OVIRS
	C-O stretch	6.3 - 6.7	0.9	OTES
	C-O bend	11.1 - 11.4 13.3 - 14.0 27.0 - 31.0	0.7 0.4 9 - 17	OTES
Sulfates	Ferric pigment	0.4 - 0.6	0.2	OVIRS
	Fe^{3+} electronic absorptions	0.44, 0.95	0.02, 0.40	OVIRS
	Combination & overtones of H_2O and metal-OH fundamental vibrational modes	1.48 - 2.21	variable	OVIRS
	S-O stretches	8 - 12	1.0 - 2.5	OTES
	S-O bends	14 - 25	variable	OTES
	Lattice vibrations (incl. metal - O)	>18 - 20	variable	OTES
Silicates	Electronic transitions (e.g., Fe^{2+} and Fe^{3+} in pyroxene and olivine)	~1.0 and 2.0	0.3 - 0.5, 1.0	OVIRS
	Si-O stretches	8 - 12	variable	OTES
	Si-O bends	15 - 20	variable	OTES
	Chain and lattice modes	>15	variable	OTES
Oxides	Fe^{3+} electronic transitions	0.35 - 1.00	0.02 - 0.4	OVIRS
	Metal-O fundamental vibrations	>12.5	variable	OTES
PAHs	Aromatic C-H stretch	3.29	0.03	OVIRS
Aliphatic hydrocarbons	$-CH_3$-groups, asymmetric C-H stretch	3.38	0.02	OVIRS
	$-CH_3$-groups, asymmetric C-H stretch	3.42	0.02	OVIRS
	$-CH_3$-groups, asymmetric C-H stretch	3.48	0.01	OVIRS
	$-CH_3$-groups, asymmetric C-H stretch	3.50	0.01	OVIRS

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MRD-306	3.3.24	Global Color Maps			
MRD-141		OSIRIS-REx shall, for > 80% of the asteroid surface, map the surface in a panchromatic filter at < 1 m resolution and map the ECAS b-v color index, v-x color index, and the depth of the 0.7-microns absorption feature, relative to one or more recognized ECAS standard stars, with an accuracy of < 2% in regions where the signal-to-noise ratio is >100 at a spatial resolution of < 2 m.	These photometric properties provide basic information about the chemistry, mineralogy, and diversity of the asteroid.	Mission System, OCAMS, SPOC	PLRA42
MRD-352	3.4	Bennu Environment Characterization Requirements			
MRD-307	3.4.1	Dust and Gas Plume Search			
MRD-142		OSIRIS-REx shall search for dust and gas plumes originating from the asteroid surface, and characterize their source regions and column densities.	Presence and location of dust and gas plumes are needed for safety assessment. Any sign of activity is essential for understanding the geologic and dynamic history of the asteroid and inform sample-site selection.	Mission System, Ground System, SPOC	PLRA43 PLRA62
MRD-308	3.4.2	Dust and Gas Plume Spectral Characterization			
MRD-143		OSIRIS-REx shall characterize the spectral properties of any detected dust and gas plumes.	Gas-phase molecules may have strong absorption and emission features in the spectral regions of interest, allowing definitive identification of certain species.	OVIRS, OTES, Ground System, SPOC	PLRA43
MRD-309	3.4.3	Natural Satellite Search			
MRD-144		OSIRIS-REx shall detect with > 95% confidence natural satellites > 10cm diameter with albedo > 0.03 within 35km of Bennu.	Presence and orbit of satellites are needed for safety assessment. Detection of any satellite allows detailed mapping of the asteroid gravity field prior to orbital insertion; presence of satellites important to constrain dynamical history. 35km represents the maximum size of the Hill Sphere based on current knowledge of the mass of Bennu. Expect 10-cm satellites to be on stable orbits only out to ~16 km from Bennu.	OCAMS, Mission System, Ground System, SPOC	PLRA44 PLRA63
MRD-311	3.4.4	Natural Satellite Light Curves			
MRD-146		OSIRIS-REx shall produce four light curves of detected satellites by measuring the time variation in their irradiance in four distinct wavelength regions that can be compared with observations of one or more recognized ECAS standard stars in the b, v, w, and x ECAS filters.	Irradiance variation provides information on rotation state of satellites as well as longitudinal albedo variation. This wavelength region allow distinction among the different asteroid spectral types.	OCAMS, Ground System, SPOC	PLRA44
MRD-312	3.4.5	Natural Satellite Spectral Properties			
MRD-147		OSIRIS-REx shall measure the integrated spectral properties of detected satellites and compare them to those of Bennu.	Spectral comparison with primary asteroid will allow determination of relationship between primary and secondary.	OVIRS, OTES, Ground System, SPOC	PLRA44
MRD-313	3.4.6	Natural Satellite Color Properties			

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MRD-148		OSIRIS-REx shall, for detected satellites, determine their average ECAS b-v color index, v-x color index, and the depth of the 0.7-micron absorption feature, relative to one or more recognized ECAS standard stars.	These photometric properties provide basic information about the chemistry, mineralogy, and diversity of the satellite and relationship with the parent asteroid.	OCAMS, Ground System, SPOC	PLRA44
MRD-271	3.4.7	Natural Satellite Orbital Properties			
MRD-196		OSIRIS-REx shall determine the orbital properties and stability of detected satellites.	The orbital properties of asteroid satellite provide an independent means to determine the gravity field and constrain the asteroid dynamic history.	Ground System, SPOC	PLRA44 PLRA63
MRD-314	3.4.8	Variation in Corrected and Normalized Spectra of Bennu			
MRD-149		OSIRIS-REx shall, for > 80% of the asteroid surface, map the variation in spectral properties in regions where the albedo is > 1% using photometrically corrected (to 30° phase angle) and normalized (at 1.3 microns) reflectance spectra over a wavelength span of at least 0.3 microns within the region 0.4 - 1.5 microns with < 5% accuracy and < 2% precision.	Photometrically corrected and normalized spectra over this wavelength range are needed to assess the effects of space weathering on the asteroid surface.	Mission System, OVIRS, SPOC	PLRA45
MRD-541	3.4.9	Space Weather Map			
MRD-542		OSIRIS-REx shall analyze the photometrically corrected and normalized spectra of the asteroid surface and map the spatial variability of space weathering.	Space weathering changes the spectral properties of the asteroid surface. Effects should predominately act on slope and albedo in the 0.4 - 1.5 microns region. An accuracy of 5% in the measurement of the spectral slope constrains space weathering on Bennu relative to what is currently understood for the most typical cases of space weathering (S-types). A CV3 meteorite with similar spectral character to Bennu may be a good analogue, and if so, slope variation could reach 3-4%/100 nm, requiring 2% precision.	SPOC	PLRA45
MRD-353	3.5	Yarkovsky Effect Measurement Requirements			
MRD-315	3.5.1	Measurement of Yarkovsky Acceleration			
MRD-150		OSIRIS-REx shall measure the Yarkovsky acceleration of Bennu with a Signal-to-Noise >400.	A SNR of 400 provides a factor of 2 improvement over current precision and provides a meaningful refinement to the present impact hazard assessment.	Mission System, SPOC	PLRA46 PLRA65
MRD-316	3.5.2	Global Albedo Map			

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MRD-154		OSIRIS-REx shall, for > 80% of the asteroid surface, map the global albedo using the absolute flux of reflected radiation from 0.4 - 2 microns with < 5% accuracy at spatial resolution < 50m.	The amount of reflected solar radiation allows calculation of the amount of solar energy input into the regolith. The thermal emission of Bennu starts to pick up beyond 2 microns and the majority of solar radiation occurs below this wavelength. The known low albedo of Bennu implies that nearly all solar radiation is absorbed by the surface, 5% accuracy provides sufficient knowledge to determine energy balance in the regolith.	Mission System, OVIRS, SPOC	PLRA46
MRD-317	3.5.3	Global Temperature and Thermal Inertia Maps			
MRD-155		OSIRIS-REx shall, for > 80% of the asteroid surface, measure the absolute flux of thermally emitted radiation with < 3% accuracy and produce maps of the temperature at seven different local solar times plus the derived thermal inertia at a spatial resolution < 50m.	The peak thermal emission from Bennu occurs at ~15 microns, so the total flux can be determined by measuring well beyond this wavelength. The precision in positional prediction for Bennu requires knowledge of the distribution in emitted energy to within 3%.	Mission System, OTES, SPOC	PLRA46
MRD-318	3.5.4	Comprehensive Thermal Model			
MRD-156		OSIRIS-REx shall produce a thermal model of the asteroid to determine the radiation imbalance in the regolith and test the theory of Yarkovsky acceleration.	Accurate prediction of the long-term orbital evolution of Bennu requires detailed thermal model of the asteroid.	SPOC	PLRA46
MRD-354	3.6	Bennu Integrated Global Properties Characterization Requirements			
MRD-319	3.6.1	Bennu Light Curve Measurement			
MRD-157		OSIRIS-REx shall produce four light curves of Bennu by measuring the variation in its irradiance over two rotation periods to within < 3% relative brightness in four distinct wavelength regions that can be compared with observations of one or more recognized ECAS standard stars in the b, v, w, and x ECAS filters.	Irradiance variation with time provides information on rotation state of asteroid as well as longitudinal albedo variation. A 3% relative variation between different wavelength bands allows differentiation between known asteroid taxonomies.	Mission System, OCAMS, SPOC	PLRA47
MRD-320	3.6.2	Bennu Phase Function Measurement			
MRD-158		OSIRIS-REx shall produce four phase functions of Bennu by measuring the variation in its irradiance over a minimum of ten degrees change in phase angle, to within < 3% relative brightness in four distinct wavelength regions that can be compared with observations of one or more recognized ECAS standard stars in the b, v, w, and x ECAS filters.	Irradiance variation with phase angle provides information on phase function of the asteroid as well as albedo variation.	Mission System, OCAMS, SPOC	PLRA47
MRD-321	3.6.3	Measurement of Integrated Spectral Properties of Bennu			
MRD-159		OSIRIS-REx shall measure the integrated spectral properties of Bennu over one rotation period to detect spectral features listed in MRD-159 Table (Absorption Features of Key Mineralogical & Organic Molecules) below with > 5% absorption depth.	Spectral variation with time provides information on longitudinal variation of surface and allows for direct comparison with telescope data.	Mission System, OVIRS, OTES, SPOC	PLRA47

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MRD-532		MR-159 Table Absorption Features of Key Mineralogical & Organic Molecules			

Material	Selected Modes	Band Center (µm)	Band Width (µm)	Instrument
H_2O adsorbed on grains	O-H stretch	2.95	0.28	OVIRS
	H-O-H bend	6.15	0.2	OTES
Phyllosilicates	O-H stretch from structural OH	2.74	0.03	OVIRS
Carbonates	Internal and lattice vibrations	>1.6	variable	OVIRS
	C-O stretch	6.3 - 6.7	0.9	OTES
	C-O bend	11.1 - 11.4 13.3 - 14.0 27.0 - 31.0	0.7 0.4 9 - 17	OTES
Sulfates	Ferric pigment	0.4 - 0.6	0.2	OVIRS
	Fe^{3+} electronic absorptions	0.44, 0.95	0.02, 0.40	OVIRS
	Combination & overtones of H_2O and metal-OH fundamental vibrational modes	1.48 - 2.21	variable	OVIRS
	S-O stretches	8 - 12	1.0 - 2.5	OTES
	S-O bends	14 - 25	variable	OTES
	Lattice vibrations (incl. metal - O)	>18 - 20	variable	OTES
Silicates	Electronic transitions (e.g., Fe^{2+} and Fe^{3+} in pyroxene and olivine)	~1.0 and 2.0	0.3 - 0.5, 1.0	OVIRS
	Si-O stretches	8 - 12	variable	OTES
	Si-O bends	15 - 20	variable	OTES
	Chain and lattice modes	>15	variable	OTES
Oxides	Fe^{3+} electronic transitions	0.35 - 1.00	0.02 - 0.4	OVIRS
	Metal-O fundamental vibrations	>12.5	variable	OTES
PAHs	Aromatic C-H stretch	3.29	0.03	OVIRS
Aliphatic hydrocarbons	-CH_3-groups, asymmetric C-H stretch	3.38	0.02	OVIRS
	-CH_3-groups, asymmetric C-H stretch	3.42	0.02	OVIRS
	-CH_3-groups, asymmetric C-H stretch	3.48	0.01	OVIRS
	-CH_3-groups, asymmetric C-H stretch	3.50	0.01	OVIRS

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MRD-543	3.6.4	Bennu Integrated Thermal Inertia			
MRD-544		OSIRIS-REx shall, for one Bennu rotation period, measure the integrated absolute flux of thermally emitted radiation with < 3% accuracy and derive the thermal inertia of Bennu.	Bulk thermal inertia is an input to the Yarkovsky model and provides a point of reference to the spatially resolved measurements.	Mission System, OTES, SPOC	PLRA47
MRD-545	3.6.5	Comparison of Bennu Mission Data with Design Reference Asteroid			
MRD-546		OSIRIS-REx shall compare the astrometric, photometric, and spectroscopic properties of Bennu measured during the asteroid encounter to the ground-based and space-based telescopic data.	Calibration and improvement of telescopic characterization of asteroids is a key objective of OSIRIS-REx.	SPOC	PLRA47
MRD-355	4	Mission System Requirements			
MRD-356	4.1	General			
MRD-199	4.1.1	Mission Life			
MRD-3		OSIRIS-REx shall accomplish a 7.1-year flight mission plus 2 years of sample curation and analysis.	A 7.1-year flight time is required to meet launch period and Earth-return orbital mechanics constraints, and to provide sufficient time and margin at Bennu to conduct all science observations and collect a sample. 2 years of sample curation is required to support OSIRIS-REx science sample analysis.	Mission System, Flight System, Ground System, Spacecraft, MSA, FDS, Curation	PLRA72 PLRA73 PLRA76
MRD-346	4.1.2	Mission Life for Science Instruments			
MRD-186		The Science Instruments shall meet full performance requirements through the time the sample is stowed in the SRC (approximately Launch + 4.8yrs).	After the sample is stowed in the SRC, the science instruments are no longer needed to meet requirements.	Mission System, Flight System, OCAMS, OVIRS, OTES, OLA, Ground System	PLRA72 PLRA73
MRD-329	4.1.3	Data Quality			
MRD-167		OSIRIS-REx shall deliver > 95% of collected data to the project database.	Covers end-to-end data collection & transfer. Collected means stored in spacecraft memory.	Flight System, Ground System	MRD-77
MRD-357	4.2	Phase 1 - Launch			
MRD-208	4.2.1	Launch Vehicle			
MRD-25		OSIRIS-REx shall be compatible with EELV requirements as defined in the OSIRIS-REx Launch Vehicle ICD, OSIRIS-REx-ICD-0007.	Needed to ensure compatibility between the flight system and the launch vehicle	Spacecraft, FDS	PLRA81
MRD-501	4.2.1.1	Maximum Launch C3			
MRD-502		OSIRIS-REx shall launch with a C3 < = 29.3km2/s2.	C3 of 29.3km2/s2 permits lower Outbound Cruise delta-V relative to other C3 values	FDS	MRD-25
MRD-226	4.2.2	Flight System Wet Mass			

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MRD-57		OSIRIS-REx shall have a wet mass at launch, including payload, of <= 2110kg.	Atlas V 411 can support up to 2110 kg for the OSIRIS-REx-specific launch conditions, including a 30-minute daily launch window. 2110 kg allows filling of the tanks if the dry mass remains below 860 kg	Flight System, Spacecraft, FDS	MRD-25
MRD-209	4.2.3	Launch Period			
MRD-26		OSIRIS-REx shall launch within the period that opens in September 2016.	This launch period permits rendezvous with Bennu while keeping the flight system wet mass within launch vehicle constraints.	Spacecraft, OCAMS, OVIRS, OTES, OLA, REXIS, FDS, DSN	PLRA72
MRD-323	4.2.4	Minimum Launch Period Length			
MRD-161		OSIRIS-REx shall have a launch period of at least 21 days.	21 days has been minimum launch period length on prior planetary missions.	Spacecraft, FDS	MRD-25
MRD-358	4.3	Phase 3 - Approach			
MRD-198	4.3.1	Bennu Acquisition			
MRD-227	4.3.2	Star Detection Visual Magnitude			
MRD-61		OSIRIS-REx shall detect stars at a visual magnitude of > 11 with a signal-to-noise of > 7.	Enables starfield optical navigation on approach to Bennu.	OCAMS, Pointing	MRD-504
MRD-228	4.3.3	Bennu Rendezvous			
MRD-62		OSIRIS-REx shall reach a range of 6500 +/- 200km (1-sigma) from Bennu with a 5 +/- 1m/s (1-sigma) approach speed relative to Bennu.	"Rendezvous" occurs when the state specified in this requirement is achieved, nominally at the end of Asteroid Approach Maneuver #2 (AAM2). A range of 6300km permits a 28-day approach to within 18km of Bennu, permitting the Integrated Properties science campaign to be accomplished as well as the > 10cm natural satellite survey. This range and approach speed also provides at least 14 days for the operations team to refine and execute AAM3.	Mission System, Ground System, Spacecraft, FDS	MRD-425 MRD-548
MRD-503	4.3.3.1	Starfield-based Optical Navigation			
MRD-504		OSIRIS-REx shall perform starfield-based optical navigation at Bennu.	Needed to determine the spacecraft state relative to Bennu during Approach and Survey phases.	Mission System, Flight System, Ground System, Pointing, FDS	MRD-62 MRD-160
MRD-224	4.3.4	Surface Contact Avoidance			
MRD-45		OSIRIS-REx shall, during all mission phases except Reconnaissance, TAG Rehearsal, and Sample Collection, use trajectories that avoid contact with Bennu for > 5 days.	Uncontrolled contact with Bennu could result in unrecoverable damage to the spacecraft.	FDS	MRD-3
MRD-424	4.3.5	Bennu Phase Function Data Collection			

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MRD-425		OSIRIS-REx shall collect OCAMS data in each of 4 colors from an approach range between 50,000km and 6,000km at < 0.1° solar phase angle increments and will position the spacecraft such that the solar phase angle relative to Bennu varies by > 10° and falls between 15° and 70°.	Ensures sufficient illumination and phase angle variation for RQ36 phase function measurement.	Mission System, Spacecraft, Ground System, FDS, OCAMS	MRD-158
MRD-547	4.3.6	Bennu Light Curve Data Collection			
MRD-548		OSIRIS-REx shall collect OCAMS data in the v-filter in 1° increments, and in the b, w, and x-filters in 5° increments over two Bennu rotation periods from an approach range between 50,000km and 6,000km and with a solar phase angle < 70°.	Needed for RQ36 light curve measurement.	Mission System, Spacecraft, Ground System, FDS, OCAMS	MRD-157
MRD-549	4.3.7	Bennu Integrated Vis-IR Data Collection			
MRD-550		OSIRIS-REx shall collect OVIRS data when the angular size of Bennu reaches > 1mrad on approach, over one rotation period.	Needed for measurement of spectral features over Bennu disk.	Mission System, Spacecraft, Ground System, OVIRS	MRD-159
MRD-551	4.3.8	Bennu Integrated Thermal-IR Data Collection			
MRD-552		OSIRIS-REx shall collect OTES data when the angular size of Bennu reaches > 2mrad on approach, over one rotation period.	Needed for measurement of spectral features and thermal inertia over Bennu disk.	Mission System, Spacecraft, Ground System, OTES	MRD-159MRD-544
MRD-322	4.3.9	Approach Speed for Natsat Survey			
MRD-160		OSIRIS-REx shall reduce approach speed to 19cm/s +/- 4cm/s (1-sigma) at a range of 250 +/- 10 km (1-sigma).	Permits time for >= 10cm natural satellite survey prior to entering within 20km range of Bennu	Mission System, Spacecraft, Ground System, FDS	MRD-144 MRD-550 MRD-552
MRD-393	4.3.10	Solar Phase Angle for > 10cm Natsat Survey			
MRD-394		OSIRIS-REx shall position the spacecraft such that the solar phase angle relative to Bennu is < 25° during 10cm natural satellite survey operations.	Ensures any natural satellites present, within the size range of interest, are sufficiently illuminated to permit a S/N > 2 detection.	Spacecraft, Ground System, FDS	MRD-144
MRD-396	4.3.11	Images per Field for NatSat Surveys			
MRD-397		OSIRIS-REx shall image 5 times with MapCam each of the natural satellite search fields.	Five images of each search field is needed to detect with 95% confidence the existence of satellites.	Ground System	MRD-144
MRD-229	4.3.12	> 10cm Natsat Survey Coverage			
MRD-63		OSIRIS-REx shall image up to 16 separate fields every 1 hour for 5 hours during a natural satellite search.	16 separate fields represents the stressing case for spacecraft performance of a natural satellite search. Assumes a 25 deg solar phase angle and Sun-Bennu range of 1.1 AU.	OCAMS, Spacecraft, Ground System	MRD-144

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MRD-359	4.4	Phase 4 - Survey			
MRD-426	4.4.1	Preliminary Survey Mass Estimation			
MRD-427		OSIRIS-REx shall estimate the mass of Bennu to within 2% (1-sigma) prior to the end of the Preliminary Survey Phase.	Required for insertion into Orbital A.	Mission System, FDS	MRD-28 MRD-429
MRD-231	4.4.2	Preliminary Survey Flybys			
MRD-65		During the Preliminary Survey Phase, OSIRIS-REx shall execute three flybys of Bennu with a closest approach radius of 7.0 +/- 0.4km (2σ), one over the north pole, one over the south pole, and one over the equator.	Permits Bennu mass determination to 2%.	Spacecraft, Ground System, FDS	MRD-427
MRD-232	4.4.3	Preliminary Survey Flyby Radiometric Tracking			
MRD-66		During each Preliminary Survey flyby, OSIRIS-REx shall maintain a continuous radiometric tracking link for > 1hr centered on the time of closest approach to Bennu.	Permits mass determination to 2% by eliminating trajectory perturbations due to spacecraft slews and propulsive manuevers.	Spacecraft	MRD-427
MRD-507	4.4.3.1	Preliminary Survey Flyby Speed			
MRD-508		OSIRIS-REx shall execute each Preliminary Survey flyby with a Bennu-relative speed of 20 +/- 2cm/s (3-sigma).	Permits Bennu mass determination to 2%.	Spacecraft, Ground System, FDS	MRD-427
MRD-327	4.4.4	Preliminary Survey Ranging			
MRD-165		OSIRIS-REx shall provide range to the surface of Bennu with < 0.5m accuracy from a range of up to 7.39km.	Provides range for mass and initial gravity field determination in Preliminary Survey. Facilitates rapid convergence of navigation solution.	OLA	MRD-427
MRD-428	4.4.5	Global Imaging Stations			
MRD-429		OSIRIS-REx shall image Bennu at 3.8 ± 0.3km (2σ) radius for one rotation period at each of the following Bennu-referenced locations (all tolerances are 2σ): (40°N latitude, 30° east of noon local time) within +/-5° latitude, +/-10° longitude(40°N latitude, 30° west of noon local time) within +/-5° latitude, +/-10° longitude(40°S latitude, 30° west of noon local time) within +/-5° latitude, +/-10° longitude(40°S latitude, 30° east of noon local time) within +/-5° latitude, +/-10° longitude.	Range and observing angles optimized for stereo imaging.	OCAMS, Spacecraft, Ground System, FDS	MRD-121
MRD-601	4.4.6	Measurement of Earth-to-Bennu Range			
MRD-602		OSIRIS-REx shall measure the range from the Earth to the center of mass of Bennu to within 15 m at three epochs during asteroid proximity operations.	15 m provides SNR of > 400 for Yarkovsky detection.	Mission System, SPOC	MRD-150

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ID	Object Number	PLA-OSIRIS-REx-RQMT-0001, Rev J Released by CCR-0442, Dated April 14, 2015	Rationale	Subsystem Allocation	Parent ID
MRD-210	4.4.7	Global Spectral Mapping Stations			
MRD-28		OSIRIS-REx shall observe Bennu at 5.0 +/- 0.3km (2σ) radius for one rotation period at the following Bennu-referenced stations (all tolerances are 2σ): (0° sub-solar latitude, 8:40pm local time) within +/-5° latitude, +/-6° longitude (0° sub-solar latitude, 6pm local time) within +/-5° latitude, +/-6° longitude (0° sub-solar latitude, 3pm local time) within +/-5° latitude, +/-6° longitude (0° sub-solar latitude, 12:30pm local time) within +/-5° latitude, +/-6° longitude (0° sub-solar latitude, 10am local time) within +/-5° latitude, +/-6° longitude (0° sub-solar latitude, 6am local time) within +/-5° latitude, +/-6° longitude (0° sub-solar latitude, 3:20am local time) within +/-5° latitude, +/-6° longitude	Required to build spectral maps.	OCAMS, Spacecraft, Ground System, FDS	MRD-166 MRD-558 MRD-561 MRD-562 MRD-564
MRD-328	4.4.8	Detailed Survey Altimetry			
MRD-166		OSIRIS-REx shall, during the Detailed Survey Phase, collect altimetry data with < 2m sampling and < 0.5m (1-sigma) vertical precision.	Provides range and slope information within the fields-of-view of the spectrometers.	Pointing, OLA, Ground System	MRD-140 MRD-143 MRD-154 MRD-155
MRD-233	4.4.9	Survey Spectrometer Space Calibrations			
MRD-68		OSIRIS-REx shall observe deep-space with OVIRS and OTES at least 18mrad off the limb of Bennu at the beginning and end of each slew for the observations specified in MRD-562 and MRD-564.	Permits OVIRS and OTES space calibrations needed to meet measurement sensitivity requirements.Assumes 80% surface coverage requirements will be met with a sequence of alternating north-to-south and south-to-north slews.	Spacecraft, Ground System	MRD-140 MRD-149 MRD-154 MRD-155
MRD-509	4.4.10	5km Detailed Survey Slew Rate			

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ID	Object Number	PLA-OSIRIS-REx-RQMT-0001, Rev K, Released by CCR-0618, Dated March 11, 2016	Rationale	Subsystem Allocation	Parent ID
MRD-510	4.4.10.1	Maximum Slew Rate During Science Observations OSIRIS-REx shall slew at a configurable rate not greater than 2 mrad/sec (0.115 deg/sec) while conducting science observations and a slew simultaneously.	Needed to satisfy spatial resolution requirements for each instrument when slewing during science observations.	Spacecraft	MRD-562MRD-564
MRD-557	4.4.11	Global Color Image Data Collection			
MRD-558		OSIRIS-REx shall collect OCAMS data in the panchromatic filter with < 1m spatial resolution and each of 4 colors with < 2m spatial resolution over > 80% of the surface of Bennu.	Needed to produce color index and 0.7um absorption feature depth maps.	Mission System, Pointing, OCAMS, Ground System	MRD-141
MRD-560	4.4.12	Bennu Limb Image Data Collection			
MRD-561		OSIRIS-REx shall collect OCAMS panchromatic data with < 2m spatial resolution and > 13.0 magnitude/arcsec2 sensitivity off the limb of Bennu in < 15° (goal of 10°) increments over two rotation periods.	Needed to detect possible dust and gas plumes emanating from the surface.	Mission System, Pointing, OCAMS, Ground System	MRD-142
MRD-559	4.4.13	Bennu Vis-NIR Spectral Data Collection			
MRD-562		OSIRIS-REx shall collect OVIRS data with < 50m spatial resolution over > 80% of the surface of Bennu at the following local solar times: 10am, 12:30pm, 3pm.	Needed for spectral feature and global albedo maps.	Mission System, Pointing, OVIRS, Ground System, Spacecraft	MRD-140 MRD-149 MRD-154
MRD-563	4.4.14	Bennu Thermal-IR Spectral Data Collection			
MRD-564		OSIRIS-REx shall collect OTES data with < 50m spatial resolution over > 80% of the surface of Bennu at the following local solar times: 3:20am, 6am, 10am, 12:30pm, 3pm, 6pm, and 8:40pm.	Needed for spectral feature, temperature, and thermal inertia maps.	Mission System, Pointing, OTES, Ground System, Spacecraft	MRD-140 MRD-155
MRD-360	4.5	Phase 5 - Orbital			
MRD-234	4.5.1	Navigation Checkpoint Orbit			
MRD-69		OSIRIS-REx shall insert the flight system into an orbit between 1.4km and 5km in radius.	Permits assessment of orbital stability and calibration of small forces model from a safe distance < 5km.	Spacecraft, Ground System, FDS	MRD-70
MRD-235	4.5.2	Science / Safe Home Orbit			
MRD-70		OSIRIS-REx shall insert the flight system into a circular terminator orbit with a nominal 1.0 km mean radius.	Provides the detailed topographic mapping orbit as well as the "Safe Home" orbit from which sampling rehearsals and sorties are launched.	Spacecraft, Ground System, FDS	MRD-134 MRD-567
MRD-278	4.5.3	Configuration for 3-day Gravity Field Mapping Periods			
MRD-187		OSIRIS-REx shall maintain a solar-pressure balanced configuration for Radio Science while in the 1.0km "Safe Home" orbit.	Solar-pressure balanced configuration minimizes disturbances on the spacecraft while mapping the gravity field.	Spacecraft, Ground System	MRD-134
MRD-279	4.5.4	Radiometric Tracking for Gravity Field Mapping			

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MRD-188		OSIRIS-REx shall perform continuous tracking of the spacecraft during Radio Science while in the 1.0km "Safe Home" orbit. "Continuous" here means either constant Doppler radio tracking in Sun- or Earth-point attitude, or OpNav image collection at regular intervals in Nadir-point attitude, exclusive of periods when the spacecraft is slewing between these attitudes.	Continuous tracking needed to map the gravity field to required accuracy.	Spacecraft, Ground System	MRD-134
MRD-565	4.5.5	Global Laser Altimetry Data Collection			
MRD-567		OSIRIS-REx shall collect OLA data with < 1m spatial and vertical resolution over > 80% of the surface of Bennu.	Needed to produce topographic map for > 80% of the surface.	Mission System, Pointing, OLA, Ground System	MRD-122 MRD-126
MRD-655	4.5.6	Orbital B Navigation Prediction Accuracy			
MRD-656		OSIRIS-REx shall predict spacecraft position in Orbital B such that predictions 24 hours after OD cutoff agree to the current (definitive) position estimates to within 20, 85, and 7 meters (goal - 6, 24, and 5 meters), all 3σ values, in radial, along-track, and cross track (orbit-normal) directions, respectively.	The threshold requirement corresponds to the maximum allowable navigation errors in the TAG error budget. The objective performance is what may be achieved if spacecraft small forces are very consistent and repeatable.	FDS	MRD-13
MRD-575	4.5.7	Candidate Sample Site Stereo Imaging			
MRD-576		OSIRIS-REx shall collect OCAMS panchromatic data with < 5cm spatial resolution over 100% of a 3σ TAG error ellipse around each of up to 12 candidate sampling sites from the 1km-radius Safe Home Orbit at ranges between 600m and 1000m. Range is the distance from the spacecraft to the observed location on the surface of Bennu. At least three image sets of each site are required for stereophotoclinometry with the following constraints: a. incidence angles between 40° and 70° (with a goal of 45° and 60°) b. incidence vectors differ by > 10° (in elevation and/or azimuth) between image sets c. incidence vectors for images within a single set are within 20° of each other (elevation and azimuth). d. emission angles < 65° e. emission vectors for one image set differ by > 10° relative to the other two	Stereo photoclinometry needed to obtain 5cm vertical resolution. Full coverage of a 3σ ellipse is required by MRD-115 and MRD-608. Due to variations in the shape of Bennu and evolution of the orbit, the observing range to the surface can vary from 600m to 1000m. Constraint 'c' ensures that for any given image set, regardless of when the images are taken, the shadows are in similar direction and of similar length.	Mission System, Pointing, Ground System, OCAMS	MRD-115 MRD-608

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MRD-617	4.5.8	Candidate Sample Site OTES Data Collection			
MRD-618		OSIRIS-REx shall collect OTES data with < 8m spatial resolution over > 80% of a 2σ TAG error ellipse around up to 12 candidate sampling sites from the 1km-radius Safe Home Orbit, at ranges between 600m and 1000m. Range is the distance from the spacecraft to the observed location on the surface of Bennu.	Needed for producing thermal inertia maps of each candidate sampling site. 80% coverage of a 2σ ellipse is required by MRD-540.	Mission System, Pointing, OTES, Ground System	MRD-540
MRD-566	4.5.9	Off-nadir Pointing from Safe Home Orbit			
MRD-568		OSIRIS-REx shall be capable of pointing the payload deck up to 20° off-nadir in any direction that intersects the sunlit surface of Bennu while the spacecraft is in the 1km Safe Home orbit, and maintaining that pointing for up to 30 minutes.	Off-nadir pointing toward the sunlit surface of Bennu is required for optical navigation imaging and for recon observations of candidate sample sites with OCAMS and OTES. STK simulation of observations of 12 sites, using radar-derived shape model of Bennu, show a maximum nadir off-point angle for the spacecraft of 20 degrees, and an observing time of 30 minutes to ensure coverage requirements are met.	Spacecraft, Ground System	MRD-516 MRD-576 MRD-618
MRD-361	4.6	Sample Site Selection			
MRD-569	4.6.1	Sample Site Selection			
MRD-570		OSIRIS-REx shall select a sample site that satisfies the following criteria: a. >99% probability of ensuring the safety of the flight system during sampling and b. >80% probability of acquiring > 60g of bulk sample per sampling attempt.	a. 1% is the project's tolerance for mission failure during TAG due to unsafe surface conditions, with the likelihood of surviving n attempts being Psurv=0.99^n. b. An 80% chance of success per attempt provides for a >99% likelihood of encountering sampleable material in three sampling attempts. The likelihood of acquiring > 60g in n sampling attempts is Psamp=1-(0.2)^n. For 3 attempts that likelihood is 1 – (0.2)^3 = 0.992.	Mission System, Ground System	MRD-14 MRD-112 MRD-113
MRD-219	4.6.2	Sampleable Surface Angle			
MRD-40		OSIRIS-REx shall be capable of obtaining a sample with a surface angle < 14°. Surface angle is defined as the angle between a 32 cm diameter sample area average normal vector and the commanded spacecraft negative Z-axis.	Constrains sampleable sites to those with surface variation of less than 14 degrees, which is the allocation from TAGSAM 15 degree capability to self-align with the surface. This surface variation includes local slopes on the scale of the TAGSAM Head, surface curvature due to navigation delivery errors, and rocks that could tilt the TAGSAM Head at contact.	Spacecraft	MRD-570
MRD-243	4.6.3	Sampleable Regolith Grain Size			
MRD-80		OSIRIS-REx shall obtain a sample in a region with > 80% probability of the TAGSAM contacting grains that are < 2cm in their longest dimension.	This requirement is needed to ensure the regolith at the sample site is indeed sample-able by TAGSAM. 2cm is the largest grain size that can fit within the smallest dimension of the TAGSAM throat.	Spacecraft	MRD-570

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MRD-220	4.6.4	Telemetry Coverage for TAG			
MRD-41		OSIRIS-REx shall maintain continuous telemetry coverage of the TAG sequence from the start of the checkpoint maneuver through initial surface contact.	Provides telemetry for event reconstruction in the event of a failure near the surface of Bennu.	Spacecraft, Ground System	MRD-99 MRD-102
MRD-571	4.6.5	Safe Surface Angle for Sampling			
MRD-573		OSIRIS-REx shall attempt sample collection in a region with < 1% probability of the TAGSAM contacting a surface angle > 14°. Surface angle is defined as the angle between a 32 cm diameter sample area average normal vector and the commanded spacecraft negative Z-axis.	Constrains safe sites to those with surface variation of less than 14°. This surface variation includes local slopes on the scale of the TAGSAM Head, surface curvature due to navigation delivery errors, and rocks that could tilt the TAGSAM Head at contact. Safety constraint permits rocks up to 6.4cm in height under the TAGSAM Head.	Spacecraft, Ground System, FDS	MRD-570
MRD-572	4.6.6	Maximum Rock Height for Sampling			
MRD-574		OSIRIS-REx shall be capable of obtaining a sample in the presence of a rock within the TAGSAM head circumference that is 5cm high and attempt sample collection in a region with < 20% probability of the TAGSAM contacting a rock > 5cm high.	Rocks taller than 5cm cause the TAGSAM head to tilt. The gap created by such a tilt degrades the sample collection efficiency of the TAGSAM.	Spacecraft	MRD-570
MRD-612	4.6.7	Maximum Rock Diameter for Sampling			
MRD-611		OSIRIS-REx shall attempt sample collection in a region with < 20% probability of the TAGSAM contacting a rock > 21cm in its longest dimension parallel to the sampling plane. The sampling plane is the plane normal to which the spacecraft negative Z-axis is commanded for TAG, defined by the 2σ TAG delivery error ellipse average normal vector.	21cm is the diameter of the TAGSAM collection inlet (inner diameter). A rock > 21cm in diameter could completely block the inlet and prevent sample collection.		MRD-570
MRD-362	4.7	Phase 6 - Reconnaissance			
MRD-211	4.7.1	Safeing Maneuver			
MRD-29		OSIRIS-REx shall provide the option to maneuver away from Bennu if the Flight System enters Safe Mode.	If a safing event occurs during Bennu proximity operations, maneuvering away from Bennu ensures the spacecraft will not come in contact with the asteroid. It is expected that this option will not be used for all safe mode entries. Exceptions would be some of the hyperbolic fly-bys.	Spacecraft, Ground System, FDS	MRD-3
MRD-236	4.7.2	Sample Site Recon Trajectory			

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MRD-73		OSIRIS-REx shall conduct reconnaissance of candidate sampling sites at ranges of 525 +/- 50m (2-sigma) and 225 + 140m /- 25m (2-sigma). Range is the distance from the spacecraft to the observed location on the surface of Bennu.	525m permits OCAMS and OLA to meet spatial and vertical resolution requirements while ensuring sample error ellipse coverage with OVIRS and OTES. 225m permits OCAMS to collect sub-cm resolution images. Tolerances on range permit spatial resolution and coverage requirements to be met within flight dynamics targeting capability. For an equatorial site, the range variation during a nominal flyover is 135m. The range error in the trajectory is < +/-15m, 2-sigma. Accounting for these two errors and setting the minimum range at 200m yields a maximum range of 365m.	Spacecraft, Ground System, FDS, OCAMS, OLA	MRD-56MRD-576MRD-578MRD-582MRD-583
MRD-225	4.7.3	Recon Site Laser Altimetry Data Collection			

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MRD-56		OSIRIS-REx shall collect OLA data with < 5cm spatial resolution and < 5cm (1-sigma) vertical precision over a 3σ TAG error ellipse around at least the prime sampling site from a range of 500m. Range is the distance from the spacecraft to the observed location on the surface of Bennu.	Needed to assess candidate sample sites against 14° sampling angle and 5cm rock height criteria on the scale of the TAGSAM Head (32cm).	Mission System, Pointing, OLA, Ground System	MRD-115 MRD-608
MRD-577	4.7.4	Recon Site < 2cm Resolution Image Data Collection			
MRD-578		OSIRIS-REx shall collect PolyCam data over > 80% of a 2σ TAG error ellipse around at least the prime and backup sampling sites from a nominal range of 225m. Range is the distance from the spacecraft to the observed location on the surface of Bennu.	This requirement drives the reconnaissance scan strategy. Covering > 80% of a 2σ TAG error ellipse provides the coverage needed to satisfy MRD-116.	Mission System, Pointing, Ground System, Spacecraft	MRD-116
MRD-642	4.7.5	Imaging Resolution for Sampleability Assessment			
MRD-643		OSIRIS-REx shall achieve a spatial resolution not greater than 0.9cm over 3 pixels at a range of 200m. Range is the distance from the spacecraft to the observed location on the surface of Bennu.	Needed to specify the expected resolution at the low end of PolyCam's focus range.	OCAMS	MRD-116
MRD-579	4.7.6	Recon Site Spectral Data Collection			
MRD-582		OSIRIS-REx shall collect OVIRS and OTES data with < 5m spatial resolution over > 40% of a 2σ TAG error ellipse around at least the prime sampling site from a nominal range of 525m. Range is the distance from the spacecraft to the observed location on the surface of Bennu.	Needed for science value assessment of each candidate sample site by mapping the chemistry and minerology of each site.	Mission System, Pointing, Spacecraft, OVIRS, OTES, Ground System	MRD-118
MRD-580	4.7.7	Recon Site Color Image Data Collection			
MRD-583		OSIRIS-REx shall collect OCAMS data in the panchromatic filter with < 25cm spatial resolution and in each of 4 colors with < 50cm spatial resolution over > 80% of a 2σ TAG error ellipse around at least the prime sampling site from a nominal range of 525m. Range is the distance from the spacecraft to the observed location on the surface of Bennu.	Needed for science value assessment of each candidate sample site by mapping the chemistry and minerology of each site.	Mission System, Pointing, Spacecraft, OCAMS, Ground System	MRD-119
MRD-581	4.7.8	Sun Incidence Angle for 225m Recon Flyovers			
MRD-584		For candidate sampling sites that fall within 70° of the sub-solar point at some time during Bennu's rotation, OSIRIS-REx shall image the site such that the sun incidence angle falls between 40° and 70° (goal of 45° and 60°), and the emission angle is not greater than 30° during a 225m recon flyover.	Needed to ensure 2cm over 5 pixel spatial resolution with a signal-to-noise ratio of at least 20. Below 40° shadows begin to shorten, limiting the edge contrast of surface features. Beyond 70° imaging degrades rapidly as shadows lengthen and the surface brightness decreases.	Spacecraft, Ground System, FDS	MRD-116
MRD-619	4.7.9	Solar Phase Angle for 525m Recon Flyover			

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MRD-620		For candidate sampling sites that fall within 40° of the sub-solar point at some time during Bennu's rotation, OSIRIS-REx shall observe the site such that the sun incidence angle at the site falls between 30° and 40° and the phase angle is not greater than 40° during a 525m recon flyover.	Needed to ensure detection of organic spectral features with > 5% absorption depth during recon flyovers. Locations where the sun incidence angle falls between 30° and 40° ensures the surface temperature remains low enough to limit the emitted radiation in the 3 – 4um portion of the OVIRS spectral band at heliocentric distances > 1AU. The combination of the incidence angle (temperature) and phase angle constraints ensures that a 5% absorption feature can be detected with 99% confidence.	Spacecraft, Ground System, FDS	MRD-118MRD-119
MRD-363	4.8	Phase 7 - TAG Rehearsal			
MRD-237	4.8.1	TAG Maneuver Rehearsal			
MRD-74		OSIRIS-REx shall rehearse and demonstrate sample collection maneuvers prior to attempting sample collection.	Needed to ensure each step in the TAG maneuver sequence is practiced and trajectories can be accurately predicted prior to committing to surface contact and sample collection. Reduces the risk of not collecting a sample.	Spacecraft, Ground System, FDS	MRD-13
MRD-280	4.8.2	Verification of Rotation Matching			
MRD-189		OSIRIS-REx shall measure the spacecraft's lateral velocity relative to the surface of Bennu after the Matchpoint maneuver to +/-0.2cm/s (1-sigma), via ground data processing after the Matchpoint rehearsal.	Verification of a maximum surface-relative velocity of 2cm/s requires a measurement accuracy 1/10th of that value.	Mission System, Ground System, FDS	MRD-13
MRD-221	4.8.3	Rotation Matching Verification Lighting			
MRD-42		OSIRIS-REx shall execute TAG with a solar phase angle < 85°.	Lighting constraints for rotation matching verification imaging. Need contrast to identify & track landmarks image to image.	Spacecraft, Ground System, OCAMS, FDS	MRD-189
MRD-212	4.8.4	Imaging after Match Point Maneuver			
MRD-30		OSIRIS-REx shall image the surface of Bennu at ranges between 26m and 30m for at least 30s after the Matchpoint maneuver during the Matchpoint rehearsal. Range is measured from the TAGSAM contact surface to the surface of Bennu.	Needed to verify that the spacecraft's lateral velocity matches that of the Bennu surface to within 2cm/s, which is the surface contact dynamics requirement for sample collection.	Spacecraft, Ground System, OCAMS	MRD-189
MRD-621	4.8.5	Match Point Maneuver Minimum Altitude			
MRD-622		OSIRIS-REx shall complete the Matchpoint maneuver at an altitude of not less than 40m from the surface of Bennu. Altitude is measured from the TAGSAM contact surface to the surface of Bennu.	Completing the Match Point maneuver at 40m altitude balances mission needs to a) meet TAG accuracy requirements, b) image the surface to measure the lateral speed of the spacecraft relative to the surface, and c) minimize hydrazine contamination of the collected sample.	Spacecraft, Ground System, FDS	MRD-30
MRD-364	4.9	Phase 8 - Sample Collection			
MRD-202	4.9.1	TAG Accuracy			

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MRD-13		OSIRIS-REx shall contact the surface within 25m of the chosen sample site with > 98.3% confidence.	This requirement is a compromise between achievable system capability (spacecraft + flight dynamics) and estimated conditions on the surface of Bennu.	Mission System, Spacecraft, Ground System, FDS	MRD-570
MRD-623	4.9.2	Autonomous Update of TAG Maneuvers			
MRD-624		OSIRIS-REx shall provide functionally redundant methods for autonomously updating the magnitude, direction and time of on-board maneuvers for Checkpoint and Matchpoint.	Needed to meet TAG accuracy requirements for position, velocity, and contact angle.	Spacecraft, Ground System, FDS	MRD-13
MRD-203	4.9.3	Bulk Sample Mass			
MRD-14		OSIRIS-REx shall acquire > 60 g of bulk sample from Bennu.	15g (MRD-105) + 45g (MRD-106) = 60 g.	Spacecraft, Mission System	MRD-105 MRD-106
MRD-204	4.9.4	Surface Contact Pad			
MRD-15		OSIRIS-REx shall provide > 26 cm2 of surface contact pad capable of acquiring particles from 10 microns to 1 mm in size while the TAGSAM Sampler Head is in contact with the asteroid surface.	6.5cm2 (MRD-112) + 19.5cm2 (MRD-113) = 26cm2.	Spacecraft	MRD-112MRD-113
MRD-213	4.9.5	Surface Contact Speeds			
MRD-31		OSIRIS-REx shall contact the surface of Bennu with a surface relative vertical speed of 10 +/- 2cm/s (3-sigma) and surface relative lateral speed of 0 +/- 2 cm/s (3-sigma) where the vertical and lateral speeds are the components of the surface relative velocity vector normal and tangential to the sampling plane, respectively. The sampling plane is the plane normal to which the spacecraft negative Z-axis is commanded for TAG, defined by the 2σ TAG delivery error ellipse average normal vector.	Approach speed above 12cm/s and lateral speed above 2cm/s coupled with low sliding friction and a surface slope > 15° relative to the sampling plane normal place a torque on the spacecraft that could result in contact of a solar panel with the surface.	Spacecraft, Ground System, FDS	MRD-14 MRD-112 MRD-113 MRD-570
MRD-625	4.9.6	Maximum Surface Contact Angle			
MRD-626		OSIRIS-REx shall achieve a contact angle not greater than 15°. The contact angle is the angle between the normal to the TAGSAM contact surface and the spacecraft's Z-axis when the nitrogen gas is released during TAG sample collection.	Allocations: 14° to surface angle; 4.4° to delivery error; 3° to spacecraft attitude error. Constraining the contact angle is needed for both spacecraft safety and regolith sampleability.	Spacecraft, Ground System, FDS	MRD-14 MRD-570
MRD-402	4.9.7	Imaging of Sample Collection Event			

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ID	Object Number	PLA-OSIRIS-REx-RQMT-0001, Rev K, Released by CCR-0618, Dated March 11, 2016	Rationale	Subsystem Allocation	Parent ID
MRD-403		OSIRIS-REx shall image the sampling site, during the sample collection event, at a rate of at least 3 frames in 5 seconds from 5m altitude through TAG + 5 sec, with a FOV > 12.5 degrees x 12.5 degrees and sub-cm resolution.	To understand the effect of TAGSAM contact and gas injection into the regolith. To capture particulate and dust movement to verify success of gas release and regolith mobilization. In addition, to document TAG contact dynamics to understand the nature of the event. In particular, to understand where contact was made and how that contact changed during the gas injection. FOV of 12.5 deg x 12.5 deg encompasses TAGSAM Head diameter at 3m range.	Pointing, OCAMS, Ground System	MRD-380
MRD-401	4.9.8	Imaging Rate on Approach from Matchpoint			
MRD-404		OSIRIS-REx shall image the surface at a continuous rate of > 0.1Hz from 30m to 5m altitude with a FOV > 12.5 degrees X 12.5 degrees.	A series of nested images during the descent is an excellent way to understand the exact location of the sampling site relative to the lower-res images of the entire asteroid and the sample-site ellipse. It will thus inform the success of the TAG event in achieving the sample site ellipse requirement and the lateral drift requirement. FOV of 12.5 deg x 12.5 deg encompasses TAGSAM Head diameter at 3m range.	Pointing, OCAMS, Ground System	MRD-380
MRD-239	4.9.9	Post-TAG Escape Maneuver			
MRD-76		OSIRIS-REx shall perform an escape maneuver from Bennu after attempting sample collection.	Reduces the risk of compromising the spacecraft via re-contact with the surface after the sample has been collected.	Spacecraft, Ground System, FDS	MRD-3
MRD-205	4.9.10	Bulk Sample Mass Verification			
MRD-16		OSIRIS-REx shall verify the mass of the bulk sample prior to stowing the sample in the SRC.	Sample acquisition must be verified prior to departure to ensure the minimum sample mass has been collected and to support the decision to make a second (and third) sampling attempt.	Spacecraft, Ground System	MRD-14
MRD-253	4.9.11	Number of Sampling Attempts			
MRD-97		OSIRIS-REx shall have the flight and ground resources to conduct at least 3 sample collection attempts.	Having the resources to conduct 3 sampling attempts permits a > 99% chance of contacting sampleable regolith and increases the likelihood of one successful sampling event.	Spacecraft, Ground System, OCAMS, FDS	MRD-14 MRD-112 MRD-113
MRD-258	4.9.12	Stow of TAGSAM Head			
MRD-103		OSIRIS-REx shall stow the TAGSAM head in the SRC prior to departing Bennu.	Permits return of the sample to the Earth's surface.	Spacecraft, Ground System	MRD-14MRD-112MRD-113
MRD-585	4.9.13	TAGSAM Head Imaging			

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MRD-586		OSIRIS-REx shall detect particles protruding 5mm or more from the TAGSAM Head contact surface with a signal-to-noise ratio not less than 100 at a range of 2.1 +/- 0.1m.	Images will show albedo changes in contact surface due to regolith material. Albedo differences will be used to estimate the area over which surface sample was collected. Images of the head taken edge-on will be used to detect particles 6mm and larger that could interfere with stowing head.	Spacecraft, Ground System, OCAMS	MRD-190
MRD-365	4.10	Phase 9 - Return Cruise			
MRD-240	4.10.1	Minimum Stay Time at Bennu			
MRD-77		OSIRIS-REx shall stay at Bennu for at least 435 days.	The DRM includes 442 days between the days of the AAM and ADM. Executing the DRM and adding 2 additional sampling attempts (including full rehearsals at each site) leaves only 7 days prior to ADM. So a minimum stay time requirement of 435 days is needed.	MSA, SPOC, FDS	MRD-14 MRD-112 MRD-113
MRD-366	4.11	Phase 10 - Earth Return & Recovery			
MRD-246	4.11.1	Stardust-Heritage Aeroshell			
MRD-88		OSIRIS-REx will re-use the Stardust Sample Return Capsule's aeroshell design.	Using a flight-proven design lowers mission risk. The Stardust SRC successfully returned samples from a comet tail to the Earth's surface.	Spacecraft	MRD-18
MRD-325	4.11.2	Maximum Re-entry Speed			
MRD-163		OSIRIS-REx shall return the Sample Return Capsule with an Earth atmosphere-relative re-entry speed < 12.4km/s.	Preserves back-up departure opportunities from Bennu in May through June of 2021.	Spacecraft, Ground System, FDS	MRD-18
MRD-214	4.11.3	Safe Return Trajectory			
MRD-32		OSIRIS-REx shall place the Flight System on an Earth return trajectory that misses Earth by > 200km until the final deterministic maneuver before Sample Return Capsule release.	NPR 8715.5, Rev. A, 3.4.2.2 states "Entry and landing shall not be initiated until all conditions critical to safety have been confirmed (Requirement)." Targeting direct entry does not satisfy this requirement.	Ground System, FDS	
MRD-206	4.11.4	Safe SRC Landing			
MRD-18		OSIRIS-REx shall safely land the Sample Return Capsule at the UTTR no later than September 30, 2023.	To leverage Stardust and Genesis heritage recovery facilities, staff, and procedures at the UTTR. A 9/30/2023 return permits 2 full years of sample curation within project budget.	Mission System, Ground System, FDS, DSN	MRD-105 MRD-106 MRD-112 MRD-113
MRD-216	4.11.5	SRC Re-entry Trajectory			

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MRD-34		OSIRIS-REx shall re-enter on a direct posigrade trajectory, with an inertial flight path angle of -8.20° +/- 0.08° (3-sigma) at an entry interface of 6503.14 km from Earth center, for landing at the Utah Test and Training Range (UTTR).	Ensures the re-entry conditions remain within the Stardust experience and hardware heritage. Posigrade re-entry also ensures DSN coverage of all pre-entry critical events. 0.07° FPA error allocated to FDS, 0.04° allocated to Spacecraft for SRC release. RSS = 0.08°. 6503.14km from Earth center corresponds to a geocentric altitude of 125 km which is outside the atmosphere at all possible entry latitudes to facilitate the transition from interplanetary trajectory propagation in a vacuum to Earth-relative trajectory propagation with full modeling of atmospheric effects.	Spacecraft, Ground System, FDS	MRD-18
MRD-244	4.11.6	Sample Temperature			
MRD-84		OSIRIS-REx shall maintain the sample at < 75°C from collection through curation.	In the sample region of +/- 55 degrees latitude, the surface and subsurface (5cm) should have seen >75 degC for several Myr. A sample temperature limit of 75 degC (348K) will preserve low-temperature mineralogy states of 360K (or higher), if present at the sample site, and leverage Stardust SRC Design Heritage.	Spacecraft, Ground System, SRC Recovery, Curation	PLRA31
MRD-215	4.11.7	Safe Disposal Trajectory			
MRD-33		After Sample Return Capsule release, OSIRIS-REx shall place the Flight System in a solar orbit with a closest approach to Earth, Moon, or any solar system body restricted by Planetary Protection, of > 250km.	Needed to comply with NASA-STD-8719.14 Section 4.6. Provides for safe spacecraft disposal.	Spacecraft, Ground System, FDS	PLRA74
MRD-513	4.11.7.1	SRC to Curation Facility			
MRD-514		OSIRIS-REx shall deliver the SRC to the JSC curation clean room and open the canister to deliver the sample to the science team within 96 hours of landing under nominal conditions. Under off nominal conditions, such as inability to fly helicopters, the recovery and delivery will be accomplished as rapidly as safely practical with a target delivery of sample to the science team within 120 hours of landing of an intact SRC.	JSC houses NASA's curatorial facilities. The Bennu sample will be curated there.	SRC Recovery, Curation	PLRA102
MRD-637	4.11.7.2	Post-return SRC Assessment			
MRD-638		OSIRIS-REx shall analyze the SRC for assessment of contamination and capsule performance.	Direct flowdown of Level 1 requirement.	Curation, SRC Recovery	PLRA103 MRD-103
MRD-367	4.12	Non - Phase Specific Requirements			
MRD-223	4.12.1	Sun Keep-Out Zone, Instrument Collecting Data			
MRD-44		OSIRIS-REx shall keep the payload deck pointed > 40° from the Sun during nominal operations when any science instrument is collecting data.	Instruments can be damaged by exposure to the sun. This requirement ensures that sun-pointing does not occur during controlled science instrument operations.	Spacecraft, Ground System	MRD-186
MRD-515	4.12.1.1	Surface-Relative Navigation about Bennu			

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MRD-516		OSIRIS-REx shall perform surface-relative optical navigation during proximity operations about Bennu.	Needed to perform spacecraft orbit determination relative to the surface of Bennu, ultimately to navigate the spacecraft to the surface for sample collection.	Mission System, Flight System, Ground System, FDS	MRD-13
MRD-657	4.12.2	OpNav Image Time-Tag Accuracy			
MRD-658		OSIRIS-REx shall determine the UTC start time of the exposure of images used for Optical Navigation to within +/- 1 second.	Specifies the overall time-tag accuracy that is required for images to be usuable for Optical Navigation.	Spacecraft, OCAMS	MRD-504 MRD-516
MRD-217	4.12.3	CCSDS Compliant Telemetry			
MRD-36		OSIRIS-REx shall apply CCSDS recommendations to all telemetry & commands between the ground and flight systems.	Standard practice. Enables use of DSN.	Mission System, Spacecraft, MSA, DSN	
MRD-254	4.12.4	Compliance with GSFC-STD-1000			
MRD-99		OSIRIS-REx shall comply with GSFC-STD-1000. Exceptions to this require waiver approval from GSFC Engineering.	GSFC institutional requirement.	Mission System, Spacecraft, OCAMS, OTES, OVIRS, OLA, REXIS, MSA, SPOC, FDS	
MRD-255	4.12.5	Planetary Protection			
MRD-100		As Category II for the outbound portion of the mission and Category V, Unrestricted Earth Return, for the sample return portion, OSIRIS-REx shall comply with the requirements in NPR 8020.12D.	NASA institutional requirement.	Spacecraft	
MRD-252	4.12.6	Flight-to-Ground ICD			
MRD-95		The OSIRIS-REx ground system shall interface with the flight system as defined in the Flight-to-Ground Interface Control Document, NFP3-PN-12-OPS-9.	Needed to ensure operational compatibility between the flight and ground systems in execution of the mission.	Spacecraft, DSN, MSA, Ground System	MRD-3 MRD-36
MRD-251	4.12.7	Deep Space Network			
MRD-94		OSIRIS-REx shall utilize the Deep Space Network (DSN) according to the OSIRIS-REx DSN Service Agreement.	Establishes the parameters & criteria for OSIRIS-REx use of the DSN.	Ground System	MRD-3
MRD-587	4.12.8	Ranging Data Precision			
MRD-589		OSIRIS-REx shall provide ranging data integrated over 600-second intervals to a precision of 10 m (3-sigma) in X-band, calibrated for media effects.	Precision required for Yarkovsky investigation (Earth to Bennu distance measurement). 9.6m (3-sigma) is allocated to the Spacecraft, and 2.8m (3-sigma) to the DSN.	Spacecraft, MSA, DSN	MRD-602
MRD-588	4.12.9	Doppler Data Precision			
MRD-590		OSIRIS-REx shall provide Doppler data integrated over 60-second intervals to a precision of 0.22mm/s (3-sigma) in X-Band, fully corrected for media and spacecraft modeling effects.	Precision required for radio science (gravity field determination). 0.2mm/s allocated to spacecraft, 0.1mm/s to DSN.	Spacecraft	MRD-134
MRD-659	4.12.10	Doppler Coverage for Maneuvers			

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MRD-660		OSIRIS-REx shall provide a minimum of 15 minutes (30 minutes goal) of coherent two-way Doppler coverage during the period 1hr before and 1hr after each ground-commanded propulsive maneuver sequence between AAM1 and the Orbital B insertion maneuver. The "maneuver sequence," including the slews to and from the maneuver attitude, is excluded from the requirement. 15 minutes of coverage is considered a goal for subsequent proximity operations maneuvers.	Ground monitoring of Doppler residuals provides ground with near real-time insight into burn performance, most importantly during early proximity operations.	Spacecraft	MRD-45
MRD-250	4.12.11	Daily Data Volume Capacity			
MRD-93		OSIRIS-REx shall downlink and ingest up to 11.0Gb of data per day.	During the Detailed Survey Phase, the maximum daily data volume downlinked is estimated at the end of Phase A was 8.43Gb. Adding 30% contingency onto 8.43Gb yields 11.0Gb.	Flight System, Ground System	MRD-166 MRD-558 MRD-562 MRD-564
MRD-635	4.12.12	Inertial Reference Frame			
MRD-636		OSIRIS-REx shall use the epoch J2000, Earth Mean Equatorial, IAU Reference Vector reference frame for the inertial reference frame.	Ensures consistency of inertial reference frame across the project.	Spacecraft, MSA, FDS, SPOC	MRD-3
MRD-368	5	Mission Segment Requirements			
MRD-369	5.1	Flight System Requirements			
MRD-257	5.1.1	NASA Payload Risk Classification			
MRD-102		The Flight System shall comply with the requirements for a Class B payload as specified in NPR 8705.4, Appendix B.	NASA institutional requirement.	Mission System, Flight System, Spacecraft, OCAMS, OTES, OVIRS, OLA	PLRA71
MRD-519	5.1.1.1	REXIS Risk Classification			
MRD-520		REXIS shall comply with the requirements for a Class D payload as specified in NPR 8705.4, Appendix B.	REXIS is a student instrument and is not required to achieve the baseline science mission. Meeting Class D requirements ensures a REXIS failure will not impact the spacecraft or other instruments.	REXIS	PLRA71
MRD-247	5.1.2	Flight System Definition			
MRD-89		The Flight System will consist of the spacecraft bus, Touch-And-Go Sample Acquisition Mechanism (TAGSAM), Sample Return Capsule (SRC) and the following instruments: OCAMS, OTES, OVIRS, OLA, and REXIS.	Includes the Flight System elements needed to meet the Flight System requirements. Established in the OSIRIS-REx Concept Study Report developed during Phase A of the project.	Spacecraft, OCAMS, OTES, OVIRS, OLA, REXIS	MRD-3
MRD-412	5.1.3	Spacecraft Dry Mass Allocation			
MRD-413		The OSIRIS-REx spacecraft bus, TAGSAM, and SRC shall have a combined total dry mass of <= 845kg.	Establishes spacecraft dry mass allocation.	Spacecraft	MRD-57

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MRD-414	5.1.4	Payload Dry Mass Allocation			
MRD-415		The OSIRIS-REx science instrument payload shall have a dry mass of <= 94.5kg.	Establishes payload dry mass allocation.	Flight System	MRD-57
MRD-416	5.1.5	Science Instrument Dry Mass Allocations			
MRD-417		Each OSIRIS-REx science instrument shall comply with its dry mass allocation as captured in its instrument-to-spacecraft IRCD.	Provides pointer to IRCD mass allocation for each instrument.	OCAMS, OVIRS, OTES, OLA, REXIS	MRD-415
MRD-418	5.1.6	Science Instrument Power Allocations			
MRD-419		Each OSIRIS-REx science instrument shall comply with its power allocation as captured in its instrument-to-spacecraft IRCD.	Provides pointer to IRCD power allocation for each instrument.	OCAMS, OVIRS, OTES, OLA, REXIS	MRD-186
MRD-256	5.1.7	Compatibility with Natural and Induced Environments			
MRD-101		The Flight System shall be compatible with the natural and induced environments as specified in the Environmental Requirements Document (PLA-OSIRIS-REx-RQMT-0002).	Needed to ensure the flight system will survive and, when applicable, meet performance requirements in all mission environments.	Spacecraft, OCAMS, OTES, OVIRS, OLA, REXIS	MRD-3
MRD-326	5.1.8	Single Fault Tolerance			
MRD-164		No single failure in the Flight System shall prevent achievement of the threshold mission.	Needed to meet risk class B payload requirements.	Flight System, Spacecraft	MRD-102
MRD-330	5.1.9	Flight System Data Quality Allocation			
MRD-168		The Flight System shall downlink > 96% of collected science data.	Provides flight system allocation of data quality degradation.	Spacecraft, DSN	MRD-167
MRD-521	5.1.9.1	Downlink Data Volume Capacity			
MRD-522		The Flight System shall downlink up to 11.0Gb of data per day.	Flight System allocation from MRD-93.	Spacecraft, DSN	MRD-93
MRD-375	5.1.10	Camera Redundancy			
MRD-21		No single failure in OCAMS shall reduce performance of more than one camera.	Needed to ensure the mission achieves threshold performance with the loss of one camera.	OCAMS	MRD-164
MRD-345	5.1.11	Maximum Sun Exposure Time for Payload Deck			
MRD-185		Between post-launch vehicle separation achievement of safe spacecraft attitude and the Bennu departure maneuver, exclusive of AAM1, the Flight System shall meet all performance requirements after exposure to the sun within a 35° half-angle cone with its boresight aligned 5° from the spacecraft's +Z axis in the -X direction for not more than 160 seconds at a slew rate not less than 8.7mrad/sec (0.5°/sec) with all instruments in safehold configuration.	This is a compromise between spacecraft and PolyCam capabilities. PolyCam's telescope baffle can be permanently damaged if exposed to the sun for more than 160 sec, or dwells with the sun in one location for too long. Note: During flight processor boot/re-boot and initialization processing, more than 160 seconds may elapse before the instruments are placed in safehold configuration and a slew rate > 0.5/sec is achieved.	Spacecraft, OCAMS, OLA, OVIRS, OTES, REXIS	MRD-186
MRD-661	5.1.12	Sun Exposure During Launch and AAM1			

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MRD-662		During AAM1, with the instruments in safehold configuration, the flight system shall meet all performance requirements after exposure to the sun as close as 25 degrees to the +Z axis on the +X side of the Y-Z plane for no more than 120 seconds.	During launch and AAM1, the sun may dwell as close as 25 degrees from the +Z axis, but we can control the roll about the +Z axis to keep the sun on the +X side of the +Z axis. The instrument teams have analyzed this case and determined that there is no concern. Polycam analysis was the driving case, and that analysis shows we are OK as long as the sun is excluded from the region within 65 degrees of the -X side of the Y-Z plane. We have chosen to completely exclude the region on the -X side of the Y-Z plane in order to provide additional margin.	Spacecraft, OCAMS, OLA, OVIRS, OTES, REXIS	MRD-186
MRD-716		During launch, prior to separation of the spacecraft from the launch vehicle upper stage and with the instruments in safehold configuration, the flight system shall meet all performance requirements after exposure to the sun as close as 24 degrees to the +Z axis within ±20 degrees of the +X side of the X-Z plane with a duration not to exceed 100 seconds.	During launch, the sun may dwell as close as 24 degrees from the +Z axis, but we can control the roll about the +Z axis to keep the sun on the +X side of the +Z axis. Polycam analysis was the driving case, and that analysis shows we are OK as long as the Sun is not just on the +X side, but it is within ±20 degrees of X. The launch vehicle ICD needs 24 degrees for 100 seconds based on separation analysis.	OCAMS, OLA, OVIRS, OTES, REXIS	MRD-186
MRD-270	5.1.13	Instrument Operating States			
MRD-197		The Flight System shall support operations of instruments per the MRD-197 Table (Instrument Operating State by Mission Phase).	The flight system must provide sufficient resources (e.g., power) to support the planned operation of the instruments during the encounter with Bennu. During some mission phases, instruments will be on and collecting data, but not to satisfy specific science requirements. In these circumstances some interface requirements may be relaxed (e.g., stray light).	Pointing, Spacecraft, Ground System, OCAMS, OLA, OVIRS, OTES, REXIS	PLRA127 MRD-186 MRD-504 MRD-516

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MRD-533	5.1.13.1	MRD-197 Table			

MRD-197 Table

	Mission Phase	Launch	Outbound Cruise			Approach						
	Mission Subphase	Calibration/ Checkout	Cruise Calibration/ Checkout	Earth Flyby 100,000km Range	Earth Flyby 1 and 3 million km Ranges	Calibration/ Checkout	Acquisition of Bennu	Star Field OpNav	Integrated Properties	1m Natural Satellite	10cm Natural Satellite	Early Shape Model
Science Payload	PolyCam	X	X	X	X	X	X	X		b/u	b/u	X
Science Payload	MapCam	X	X	X	X	X	b/u	X	X	X	X	X
Science Payload	SamCam	X	X	X	X	X						
Science Payload	OVIRS	X	X	X	X	X			X			
Science Payload	OTES	X	X	X	X	X			X			
Science Payload	OLA	X	X			X						
Science Payload	REXIS	X	X			X						
S/C Sensors	GN&C LIDAR											
S/C Sensors	StowCam											
S/C Sensors	NavCam	X	X	X	X	X						

	Mission Phase	Prelim Survey			Orbital A			Detailed Survey						
	Mission Subphase	Calibration	Flybys	OpNav	Calibration	OpNav	Global Topography and Thermal IR Mapping	Calibration	OpNav	Equatorial Spectral: +/-130deg Station	Outgassing Plume Search: +/-130deg Station	Spectral: +/-90deg	Spectral: 0, +45deg/-30deg	21cm Imaging; Color Imaging
Science Payload	PolyCam	X	X		X		O	X			b/u			X
Science Payload	MapCam	X	X		X		X	X	O		X	X	X	X
Science Payload	SamCam													
Science Payload	OVIRS				X			X			O	O	X	
Science Payload	OTES						O			X	O	X	X	
Science Payload	OLA		X				O					X	X	X
Science Payload	REXIS							X						
S/C Sensors	GN&C LIDAR													
S/C Sensors	StowCam													
S/C Sensors	NavCam	X		X	X	X		X	X					

	Mission Phase	Orbital B				Reconnaissance				TAG Rehearsal				Sample Collection			
	Mission Subphase	Calibration	OpNav	Radio Science	Surface Topography, X-ray Spectroscopy, Sample Site Recon	Calibration	Safe Home Orbit (OpNav)	225m flyover (4x)	525m Flyover (2x)	Calibration	Safe Home Orbit (OpNav)	Checkpoint Rehearsal	Matchpoint Rehearsal	Calibration	Safe Home Orbit (OpNav)	TAG	Checkout/ Stow
Science Payload	PolyCam	X			X	X		X						X			
Science Payload	MapCam	X			b/u	X		O	X			X	X	X		X	
Science Payload	SamCam	X				X							X	X		X	X
Science Payload	OVIRS	X				X		O	X			O	O	X		O	
Science Payload	OTES				X			O	X			O	O			O	
Science Payload	OLA			X	X			O	X								
Science Payload	REXIS	X			X	X	X										
S/C Sensors	GN&C LIDAR	X						X				X	X			X	
S/C Sensors	StowCam					X											X
S/C Sensors	NavCam	X	X	X		X	X			X	X	X	X	X	X	X	

X	collecting science and/or navigation data to satisfy the baseline mission
O	collecting science and/or navigation data beyond the baseline mission (NOTE: These observations take advantage of the instrument performance required to support the baseline mission and do not drive additional performance requirements or verification activities.)
b/u	back-up camera for meeting the threshold mission

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MRD-405	5.1.14	Archived Flight Hardware Materials for Contamination Assessment			
MRD-406		The Flight System shall provide to the curation facility at JSC for archive a >=1 g sample of all organic and inorganic materials containing C, K, Ni, Nd, Pb, and Sn that come into physical contact with the sample, TAGSAM head, TAGSAM launch container interior, SRC canister interior, or witness material after their final cleaning, with the following exceptions: a. Propellant and catalyst bed sufficient to perform thruster firing tests 4 times. b. The witness materials (4 identical samples of each witness). c. Materials which are < 1 g total mass on the spacecraft. d. Major TAGSAM construction materials shall be >=200g. e. Materials in line of sight may be exempted via a waiver. All materials will be identical to materials used on the flight hardware (item, type, model, lot number).	This requirement is to provide a sample of bulk materials used on, or in the manufacture of, the spacecraft (many will be spacecraft materials, common lubricants, adhesives, etc.). Materials used will potentially need to be studied after the sample is returned and distributed. Materials used for the TAGSAM head and SRC are of particular concern as well as materials (especially volatile organics) that outgas in the space environment. Only materials in physical contact with the items of concern after final cleaning are of concern. Given the limited number of materials that should be in contact (including the items themselves) this should not be onerous. A mass of 1 g is required, but is listed as <1g to avoid the necessity of careful measuring or dividing difficult to divide materials.	Spacecraft, Curation	MRD-110
MRD-370	5.2	Ground System Requirements			
MRD-371	5.2.1	General			
MRD-248	5.2.1.1	Ground System Architecture			
MRD-90		The Ground System will consist of the Mission Support Area (MSA), Science Processing and Operations Center (SPOC), Flight Dynamics System (FDS), Deep Space Network (DSN), Sample Return Capsule Recovery, and Sample Curation.	Includes the Ground System elements needed to meet the Ground System requirements. Established in the OSIRIS-REx Concept Study Report developed during Phase A of the project.	MSA, SPOC, FDS, DSN, SRC Recovery, Curation	MRD-3
MRD-249	5.2.1.2	Ground Network			
MRD-92		The Ground System shall provide network and voice connectivity between ground elements per NFP3-PN-11-OPS-8, Mission Operations Concept.	Needed to ensure communication and data transfer capability between all internal and external ground elements to support pre- and post-launch mission operations activities.	MSA, FDS, SPOC, DSN	MRD-3
MRD-536	5.2.1.3	OpNav images			
MRD-22		The Ground System shall process and prioritize OpNav images for downlink and delivery to FDS.	Reduces the lag between the time the images are taken and the updated trajectory information is available for uplink to the spacecraft.	MSA, SPOC	MRD-504 MRD-516
MRD-331	5.2.1.4	Ground System Data Quality Allocation			

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MRD-169		The Ground System shall deliver > 99% of dowlinked data to the project database.	Provides ground system allocation of data quality degradation.	MSA	MRD-167
MRD-523	5.2.1.4.1	Ingest Data Volume Capacity			
MRD-524		The Ground System shall ingest up to 11.0Gb of data per day.	Ground system allocation of MRD-93	MSA, SPOC	MRD-93
MRD-525	5.2.1.5	Data Processing Algorithms			
MRD-526		The Ground System shall validate, calibrate and process the scientific data using algorithms.	Algorithms for producing low-level science data products needed to generate higher-level products.	SPOC	MRD-183
MRD-527	5.2.1.6	Science Data to PDS			
MRD-528		The SPOC shall deliver science data products to the Planetary Data System according to the SPOC-to-PDS Interface Control Document (UA-ICD-9.4.4-101).	The PDS is NASA's repository for small body data.	SPOC	PLRA86
MRD-591	5.2.1.7	Ground System Uptime			
MRD-592		The Ground System shall have an uptime no less than 97% for all mission phases.	1% downtime for each SPOC, MSA and FDS is sufficient to satisfy the need of the mission.	MSA, SPOC, FDS, DSN	MRD-3
MRD-627	5.2.1.8	Commanding the Flight System			

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MRD-628		The Ground System shall plan, generate, validate, and radiate Flight System commands.	Needed to ensure the Ground System will support all flight operations specified in the MRD.	MSA, SPOC	MRD-3 MRD-13 MRD-16 MRD-18 MRD-28 MRD-29 MRD-30 MRD-31 MRD-32 MRD-33 MRD-34 MRD-41 MRD-42 MRD-44 MRD-56 MRD-62 MRD-63 MRD-65 MRD-68 MRD-69 MRD-70 MRD-73 MRD-74 MRD-76 MRD-84 MRD-97 MRD-103 MRD-121 MRD-142 MRD-144 MRD-160 MRD-163 MRD-166	MRD-187 MRD-189 MRD-197 MRD-394 MRD-397 MRD-403 MRD-404 MRD-425 MRD-429 MRD-504 MRD-508 MRD-516 MRD-548 MRD-550 MRD-552 MRD-558 MRD-561 MRD-562 MRD-564 MRD-567 MRD-568 MRD-573 MRD-576 MRD-578 MRD-582 MRD-583 MRD-584 MRD-586 MRD-618 MRD-620 MRD-622 MRD-624 MRD-626

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MRD-645		The Ground System shall plan, generate, validate, and radiate OCAMS commands.	Need to ensure that the Ground System generates the commands to observe Bennu with OCAMS	MSA, SPOC	MRD-28 MRD-30 MRD-63 MRD-97 MRD-142 MRD-144 MRD-186 MRD-197 MRD-397 MRD-403 MRD-404 MRD-425 MRD-429 MRD-504 MRD-516 MRD-548 MRD-558 MRD-561 MRD-576 MRD-578 MRD-583 MRD-584 MRD-586
MRD-646		The Ground System shall plan, generate, validate, and radiate OLA commands.	Need to ensure that the Ground System generates the commands to observe Bennu with OLA	MSA, SPOC	MRD-56 MRD-97 MRD-166 MRD-186 MRD-197 MRD-567
MRD-647		The Ground System shall plan, generate, validate, and radiate OTES commands.	Need to ensure that the Ground System generates the commands to observe Bennu with OTES	MSA, SPOC	MRD-68 MRD-97 MRD-186 MRD-197 MRD-552 MRD-564 MRD-582 MRD-618
MRD-648		The Ground System shall plan, generate, validate, and radiate OVIRS commands.	Need to ensure that the Ground System generates the commands to observe Bennu with OVIRS	MSA, SPOC	MRD-68 MRD-97 MRD-186 MRD-197 MRD-550 MRD-562 MRD-582 MRD-620
MRD-649		The Ground System shall plan, generate, validate, and radiate TAGCAMs commands.	Need to ensure that the Ground System generates the commands for Navcam for optical navigation, NFTCam for natural feature tracking, and StowCam for post-TAG head inspection and confirmation of sample stowage.	MSA, SPOC	MRD-97 MRD-197 MRD-516
MRD-650		The Ground System shall plan, generate, validate, and radiate REXIS commands.	Need to ensure that the Ground System generates the commands for REXIS.	MSA, SPOC	MRD-197

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MRD-629	5.2.1.9	Monitoring the Flight System			
MRD-630		The Ground System shall monitor the health and safety of the Flight System.	Needed to ensure the Ground System will monitor the health and safety of the Flight System during flight operations.	MSA, SPOC	MRD-3 MRD-13 MRD-16 MRD-18 MRD-28 MRD-29 MRD-30 MRD-31 MRD-32 MRD-33 MRD-34 MRD-41 MRD-42 MRD-44 MRD-56 MRD-62 MRD-63 MRD-65 MRD-68 MRD-69 MRD-70 MRD-73 MRD-74 MRD-76 MRD-84 MRD-97 MRD-103 MRD-121 MRD-142 MRD-144 MRD-160 MRD-163 MRD-166 MRD-187 MRD-189 MRD-197 MRD-394 MRD-397 MRD-403 MRD-404 MRD-425 MRD-429 MRD-504 MRD-508 MRD-516 MRD-548 MRD-550 MRD-552 MRD-558 MRD-561 MRD-562 MRD-564 MRD-567 MRD-568 MRD-573 MRD-576 MRD-578 MRD-582 MRD-583 MRD-584 MRD-586 MRD-622 MRD-624 MRD-626
MRD-631	5.2.1.10	Ground Support Tools for ATLO			
MRD-632		The Ground System will provide tools to support mission system assembly, test, and launch operations (ATLO).	Needed to ensure ground element provide tools essential for system-level verification and testing.	MSA, SPOC, FDS	MRD-99
MRD-633	5.2.1.11	Back-Up MSA for SRC Earth Return			
MRD-634		The Ground System shall provide a back-up MSA for SRC Earth Return.	SRC entry targeting and release requires time-critical commanding.	MSA	MRD-18

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MRD-669	5.2.1.12	Back-Up Command Capability			
MRD-670		The Ground System shall establish a backup standalone capability that can be available to command the spacecraft within 72 hours of the MSA becoming unavailable.	Previous LM missions have used JPL to provide backup commanding capability since they were using JPL provided AMMOS hw/sw. OSIRIS-REx has no backup commanding capability in the event the MSA becomes unavailable for an extended period (>36 hours) because this mission does not use the heritage AMMOS system and is managed by GSFC. The backup capability is needed to ensure flight system safety in the event the MSA is unavailable. This backup capability will be staffed by MSA personnel on a emergency basis, except for SRC Release.	MSA	MRD-3 MRD-186
MRD-671	5.2.1.13	Back-Up Telemetry Capability			
MRD-672		The Ground System shall establish a backup standalone capability that can be available to process and display spacecraft telemetry within 72 hours of the MSA becoming unavailable.	Previous LM missions have used JPL to provide backup telemetry process and display capability since they were using JPL provided AMMOS hw/sw. OSIRIS-REx has no backup telemetry capability in the event the MSA becomes unavailable for an extended period (>36 hours) because this mission does not use the heritage AMMOS system and is managed by GSFC. This backup capability is needed to ensure flight system safety in the event the MSA is unavailable. The backup capability will be staffed by MSA personnel on a emergency basis, except for SRC Release.	MSA	MRD-3 MRD-186
MRD-673	5.2.1.14	Ground Support of Autonomous TAG Systems			
MRD-674		The Ground System shall support flight checkout, calibration, and operations of functionally redundant systems for autonomously updating the Checkpoint and Matchpoint maneuvers.	Needed to ensure ground support and operations planning for both prime and backup autonomous flight systems for TAG navigation and guidance.	MSA, SPOC, FDS	MRD-624
MRD-373	5.2.2	Ground System Performance			
MRD-338	5.2.2.1	Operations Team Readiness - Bennu Rendezvous			
MRD-176		The Ground System shall, prior to launch, plan to conduct operational readiness tests (ORTs) for Bennu proximity operations beginning at Rendezvous - 2 months or earlier.	The ground team required to support proximity operations activities must be fully staffed and working at peak efficiency to support rendezvous, a critcal event. Optical acquisition of Bennu will be attempted starting at R - 2 months. Based on prior mission experience 2 months is sufficient to exercise and prepare the operations team.	MSA, SPOC, FDS, DSN	MRD-62

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MRD-337	5.2.2.2	Operations Team Readiness - SRC Earth Return			
MRD-177		The Ground System shall, prior to launch, plan to conduct operational readiness tests (ORTs) for the Earth Return & Recovery mission phase beginning at Landing - 2 months or earlier.	The ground team required to support Earth return of the flight system and SRC EDL activities must be fully staffed and working at peak efficiency to support this critcal event. Based on prior mission experience 2 months is sufficient to exercise and prepare the operations team.	MSA, FDS, SRC Recovery, Curation	MRD-18
MRD-324	5.2.2.3	Initial Search for Bennu			
MRD-162		The Ground System shall plan to attempt acquistion of Bennu optically no later than 60 days prior to Asteroid Approach Manuever #2 (rendezvous state).	Needed to bring the mission operations team to the level of performance required to support approach and rendezvous operations. Also provides the opportunity to identify and respond to any issues with the navigation process prior to acquisition of Bennu. 60-day timeline similar to NEAR and Stardust.	MSA, SPOC, FDS	MRD-62
MRD-339	5.2.2.4	Return to Operations after Contingency			
MRD-178		The Ground System will return the spacecraft to nominal operations within 21 days after the mission experiences a contingency scenario.	Needed to define the agility of the ground system to replan a significant portion of the mission in the event of a contingency.	MSA, SPOC, FDS	MRD-77
MRD-342	5.2.2.5	Parameter Update Latency			
MRD-181		The Ground System shall upload parameter updates to the spacecraft within 24 hours of final downlink of applicable tracking and science data.	Needed to ensure the capability to update maneuver and science observation parameters to accommodate navigation uncertainties during Bennu proximity operations.	MSA, SPOC, FDS	MRD-13 MRD-73 MRD-74
MRD-344	5.2.2.6	Sample Site Selection Data Products			
MRD-183		The Ground System shall produce the following data products on a global scale and for each candidate sample site in support of site selection during the encounter with Bennu: a. Safety Maps b. Deliverability Maps c. Sample-ability Maps d. Science Value Maps	The science and mission operations teams needs specific data products produced during the mission to support sample site selection.	SPOC, FDS	MRD-13 MRD-114 MRD-570
MRD-410	5.2.2.7	Thermal Model for Operations Support			

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MRD-411		The Ground System shall produce, within 7 days of final downlink of applicable data, a predicted temperature map of each candidate sampling ellipse for the estimated dates and Bennu times of day for TAG with < 5m spatial resolution and accurate to +/- 10K.	Temperature maps needed to predict temperatures to inform flight system safety during sampling.	SPOC	MRD-183
MRD-372	5.2.3	Interfaces			
MRD-333	5.2.3.1	DSN-to-OSIRIS-REx Ground ICD			
MRD-172		The DSN and OSIRIS-REx ground system shall comply with the DSN-OSIRIS-REx Mission Operations Interface Control Document, DSN Doc #875-0024.	Needed to ensure operational compatibility between the DSN and other ground system elements in execution of the mission.	DSN, MSA, SPOC, FDS	MRD-66 MRD-90 MRD-94 MRD-95 MRD-188
MRD-334	5.2.3.2	MSA-to-SPOC ICD			
MRD-173		The MSA and SPOC shall comply with the MSA-to-SPOC Interface Control Document (NFP3-PN-12-OPS-6A).	Needed to ensure operational compatibility between the MSA and SPOC in execution of the mission.	MSA, SPOC	MRD-90
MRD-335	5.2.3.3	MSA-to-FDS ICD			
MRD-174		The MSA and FDS shall comply with the MSA-to-FDS Interface Control Document (NFP3-PN-12-OPS-6C).	Needed to ensure operational compatibility between the MSA and FDS in execution of the mission.	MSA, FDS	MRD-90
MRD-336	5.2.3.4	SPOC-to-FDS ICD			
MRD-175		The SPOC and FDS shall comply with the SPOC-to-FDS Interface Control Document (UA-ICD-9.0.0-100).	Needed to ensure operational compatibility between the SPOC and FDS in execution of the mission.	SPOC, FDS	MRD-90
MRD-597	5.2.3.5	Contingency Plan for Dust and Gas Plume Characterization			
MRD-598		The Ground System shall develop a contingency plan to characterize and operate in the presence of detected dust and gas plumes.	Finding a dust or gas plume on the surface of Bennu is unlikely. However, if one is found, it could present a hazard to the spacecraft during sampling. The characteristics of the plume are also of scientific interest. So a plan needs to be established in advance to accurately locate and characterize such a plume, and adjust the nominal Mission Plan accordingly.	MSA, SPOC, FDS	MRD-142 MRD-143
MRD-599	5.2.3.6	Contingency Plan for Natural Satellite Characterization			
MRD-600		The Ground System shall develop a contingency plan to characterize and operate in the presence of detected natural satellites.	Finding a natural satellite in orbit around Bennu is unlikely. However, if one is found, it could present a hazard to the spacecraft during proximity operations. The characteristics of the satellite and its orbit are also of scientific interest. So a plan needs to be established in advance to accurately determine the orbit of and characterize such a satellite, and adjust the nominal Mission Plan accordingly.	MSA, SPOC, FDS	MRD-146 MRD-147 MRD-148 MRD-196

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MRD-675	5.2.4	Engineering Requirements for Bennu Digital Terrain Maps (DTMs) Note: In this section, individual global product requirements are identified by their specified ground sample distance, e.g., "Global 75cm DTM". The sample-site specific products are identified as "Sample Site DTMs".			
MRD-676	5.2.4.1	FDS - Global 75cm DTM Product Requirements Note: These requirements assume use of Approach and Preliminary Survey products, and some Orbital A data. Note: These requirements are intended to support FDS operations from the end of Orbital A through Orbital B insertion.			
MRD-677	5.2.4.1.1	Global 75cm DTM Ground Sample Distance			
MRD-678		The Ground System shall, for > 80% of the asteroid surface, produce a set of DTMs at < 0.75 m in ground sample distance (sample resolution). Note: Ground sample distance is defined as the sample spacing of the surface in m/pix.	Rationale: Ground sample distance of DTMs should be comparable to navigation imager(s) ground sample distance (m/px) for relevant mission phases.	SPOC	MRD-28 MRD-429 MRD-516
MRD-679	5.2.4.1.2	Global 75cm DTM Relative Accuracy (Precision)			
MRD-680		The Ground System shall, for > 80% of the asteroid surface, produce a set of DTMs with post-fit residual RMS < 0.38 m (1-sigma) for each maplet. Note: Post-fit residual of a maplet is defined as the (pixel, line) difference between predicted model and observed images of the maplet.	Rationale: The RMS post-fit residual from the DTM geometry solution should be less than 0.5 DTM pixels (1-sigma). Landmarks consist of an image spanning multiple pixels. Errors in the correlation of an OpNav image to a landmark will be introduced if there are distortions in the features of the landmark, or relative shifts in the positions of adjacent landmarks. This requirement bounds the allowable distortion of features across the landmark, or variations in the relative position shifts of nearby landmarks, which factors into the FDS landmark centerfinding error budget through errors in the correlation of OpNav images with a landmark. Note: Verifying this requirement in flight assumes use of images for shape modeling that have a better ground sample distance than the maplets (i.e., Mapcam or Polycam imaging), as well as use of OLA data.	SPOC	MRD-28 MRD-429 MRD-516
MRD-681	5.2.4.1.3	5.2.4.1.3 Global 75cm DTM Accuracy			

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MRD-682		The Ground System shall, for > 80% of the asteroid surface, produce a set of DTMs with a 3D RMS accuracy < 1m (1-sigma).	Rationale: Global accuracy of the delivered landmark centers factors into the FDS landmark-tracking error budget. Note: Accuracy will be verified in flight through analysis and/or with OLA data.	SPOC	MRD-28 MRD-429 MRD-516
MRD-683	5.2.4.1.4	Global 75cm DTM Delivery			
MRD-684		The Ground System shall provide the global 75cm DTM product to FDS within 14 days of downlink of all Preliminary Survey OCAMS and OLA data.	14 days ensures the global 75cm product is available for the transition to landmark-based optical navigation and verification of Detailed Survey-level performance prior to the end of Orbital A.	SPOC	MRD-28 MRD-429 MRD-516
MRD-685	5.2.4.2	Global 35cm DTM Product Requirements Note: These requirements assume use of imaging data up through Detailed Survey. Note: This requirement is intended to support FDS operations from Orbital B through TAG.			
MRD-686	5.2.4.2.1	Global 35cm DTM Ground Sample Distance			
MRD-687		The Ground System shall, for > 80% of the asteroid surface, produce a set of DTMs at < 0.35 m in ground sample distance (sample resolution). Note: Ground sample distance is defined as the sample spacing of the surface in m/pix.	Rationale: Ground sample distance of DTMs should be comparable to navigation imager(s) ground sample distance (m/px) for relevant mission phases.	SPOC	MRD-516 MRD-656
MRD-688	5.2.4.2.2	Global 35cm DTM Relative Accuracy (Precision)			

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ID	Object Number	PLA-OSIRIS-REx-RQMT-0001, Rev K, Released by CCR-0618, Dated March 11, 2016	Rationale	Subsystem Allocation	Parent ID
MRD-689		The Ground System shall, for > 80% of the asteroid surface, produce a set of DTMs with post-fit residual RMS < 0.18 m (1-sigma) for each maplet. Note: Post-fit residual of a maplet is defined as the (pixel, line) difference between predicted model and observed images of the maplet.	Rationale: The RMS post-fit residual from the DTM geometry solution should be less than 0.5 DTM pixels (1-sigma). Landmarks consist of an image spanning multiple pixels. Errors in the correlation of an OpNav image to a landmark will be introduced if there are distortions in the features of the landmark, or relative shifts in the positions of adjacent landmarks. This requirement bounds the allowable distortion of features across the landmark, or variations in the relative position shifts of nearby landmarks, which factors into the FDS landmark centerfinding error budget through errors in the correlation of OpNav images with a landmark. Note: Verifying this requirement in flight assumes use of images for shape modeling that have a better ground sample distance than the maplets (i.e., Mapcam or Polycam imaging) as well as use of overlapping OLA data.	SPOC	MRD-516 MRD-656
MRD-690	5.2.4.2.3	Global 35cm DTM Accuracy			
MRD-691		The Ground System shall, for > 80% of the asteroid surface, produce a set of DTMs with a 3D RMS accuracy < 0.75 m (1-sigma). Note: Accuracy is defined as the absolute uncertainty of a point with respect to the origin of the asteroid centered fixed frame.	Rationale: Global accuracy of the delivered landmark centers factors into the FDS landmark-tracking error budget. Note: Accuracy will be verified in flight through analysis and with OLA data.	SPOC	MRD-516 MRD-656
MRD-692	5.2.4.2.4	Global 35cm DTM Delivery			
MRD-693		The Ground System shall provide the global 35cm DTM product to FDS within 14 days of downlink of all Detailed Survey "Baseball Diamond" OCAMS and OLA data.	14 days ensures the global 35cm product is available early in Orbital B to demonstrate the predictive accuracy needed for Recon and TAG.	SPOC	MRD-516 MRD-656
MRD-727	5.2.4.2.5	NFT Feature Catalog			

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MRD-728		The Ground System shall produce a catalog of up to 300 NFT features consisting of the following for each feature: 1. A position defined in Asteroid Center Fixed (ACF) coordinates, 2. A 2-D array of displacement (heights) relative to a reference plane above the asteroid surface to represent the shape, 3. A 2-D array of relative albedo values to capture variations in how light reflects off the asteroid surface. Note: Relative albedo is the average of the relative surface reflectance at the given grid point computed from all images in which the grid point is visible.	This requirement ensures the production of a catalog with an adequate number of sufficiently defined features for NFT to perform its functions of Checkpoint navigation state estimate, the TAG navigation state estimate and the time of touch estimate.	MSA	MRD-13 MRD-31 MRD-624
MRD-729	5.2.4.2.6	NFT Feature Fidelity			
MRD-730		The Ground System shall produce a displacement and relative albedo array for each NFT catalog feature with sufficient fidelity to allow NFT to successfully correlate the feature. Note: Relative albedo is the average of the relative surface reflectance at the given grid point computed from all images in which the grid point is visible.	This requirement ensures correlation performance for each catalog feature is sufficient for NFT to meet requirements for the Checkpoint navigation state estimate, the TAG navigation state estimate and the time of touch estimate.	SPOC	MRD-13 MRD-31 MRD-624
MRD-731	5.2.4.2.7	NFT TAG Site DEM Accuracy			
MRD-732		The Ground System shall, for a 3-sigma TAG delivery error ellipse around each of up to 2 (1 primary and 1 backup) sampling sites, produce a DTM with vertical RMS error < 0.14 m (1-sigma).	NFT uses a coarse DEM representation of the TAG site to estimate time of touch. This DEM must have sufficient accuracy to ensure a good time of touch estimate within requirements.	SPOC	MRD-13 MRD-31 MRD-624
MRD-733	5.2.4.2.8	NFT TAG Site DEM Feature Relative Accuracy			
MRD-734		The Ground System shall, for a 3-sigma TAG delivery error ellipse around each of up to 2 (1 primary and 1 backup) sampling sites, produce a DTM with vertical RMS error < 0.14 m when compared to each of the NFT features (1-sigma).	NFT uses a coarse DEM representation of the TAG site to estimate time of touch. This DEM must be consistent with the NFT features to ensure a good time of touch estimate within requirements.	SPOC	MRD-13 MRD-31 MRD-624

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MRD-500	6	Pointing Requirements			
MRD-639		The table below summarizes the pointing requirements in this section and their allocations to the spacecraft and individual science instruments. It is provided here for reference only.			

		Requirement 5 / Allocation			Requirement 1 / Allocation			Requirement 6			
		Accuracy (mrad) 3 sigma			Knowledge (mrad) 3 sigma			Stability 3 sigma			
#	Instrument	Req	Instrument	Spacecraft	Req	Instrument	Spacecraft	Req Value (mrad)	Req Time (s)	Instrument	Spacecraft
PolyCam ==>1	Polycam boresight	3.70	1.50	1.50	1.47	0.59	0.75	0.035	1.0	0.012	0.030
	Polycam roll	15.00	6.06	6.06	5.00	2.02	2.02	0.500	1.0	0.121	0.202
OpNav ==>2	OpNav Mapcam boresight				0.50	0.20	0.44				
	OpNav Mapcam roll				5.00	2.02	2.02				
MapCam ==>3	Long Stability (natural Satellites) Mapcam boresight							0.080	10.0	0.048	0.060
	Mapcam roll							0.500	10.0	0.242	0.202
MapCam ==>3	Mapcam boresight	18.33	7.41	3.00	7.33	2.96	2.00	0.080	1.0	0.048	0.040
	Mapcam roll	15.00	6.06	6.06	5.00	2.02	2.02	0.500	1.0	0.242	0.202
SamCam ==>4	Samcam boresight	92.25	37.28	10.00	36.65	14.81	5.00	0.870	1.0	0.480	0.480
	Samcam roll	15.00	6.06	10.00	15.00	6.06	5.00	5.000	1.0	3.394	1.702
OTES ==>5	OTES boresight	4.00	1.98	1.50	2.00	1.00	1.02	0.800	2.0	0.400	0.480
	OTES roll	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
OLA ==>6	OLA boresight	4.00	1.98	1.50	1.90	1.50	0.56	0.100	1.0	0.024	0.080
	OLA roll	N/A	N/A	N/A	5.00	2.47	2.02	0.100	1.0	0.000	0.000
OVIRS ==>7	OVIRS boresight	4.00	2.00	1.50	1.00	0.49	0.66	0.400	1.0	0.221	0.230
	OVIRS roll	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
REXIS ==>8	REXIS boresight	52.00	25.74	4.00	1.90	0.94	1.25	0.860	4.0	0.292	0.425
	REXIS roll	10.00	4.95	6.06	7.00	3.46	2.02	2.300	4.0	1.236	1.302

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ID	Object Number	PLA-OSIRIS-REx-RQMT-0001, Rev K, Released by CCR-0618, Dated March 11, 2016	Rationale	Subsystem Allocation	Parent ID
MRD-433	6.1	Instrument			
MRD-434	6.1.1	Polycam			
MRD-435	6.1.1.1	PolyCam Pointing Accuracy - Science			
MRD-436		At the beginning of an in-flight observation, the flight system shall point the PolyCam boresight at the intended inertial target to within 3.70 mrad (3 sigma) with a boresight roll control of 15.00 mrad (3 sigma).	Alignment of FOV relative to mean target position or target surface features to within ~25% of the width of the field-of-view, 3-sigma, and to within 15 pixels due to the roll around the boresight.	OCAMS, Spacecraft	MRD-576 MRD-578
MRD-437	6.1.1.2	PolyCam Pointing Knowledge			
MRD-438		After the in-flight calibration data of the spacecraft and science instruments are analyzed, the combined spacecraft and PolyCam pointing shall be known to within 1.47 mrad (3 sigma) for the boresight and 5.00 mrad (3 sigma) for boresight roll of the intended target.	Knowledge of alignment of FOV relative to mean target position or target surface features to within 10% of the width of the field of view and to within 5 pixels for the boresight roll; observation of star clusters will produce more accurate knowledge capability.	OCAMS, Spacecraft	MRD-121MRD-504MRD-576MRD-578
MRD-439	6.1.1.3	PolyCam Pointing Stability			
MRD-440		During in-flight science observations of an inertial target (Bennu), the flight system shall maintain stable pointing of the PolyCam boresight such that it shall not move more than 0.035 mrad (3 sigma) with a boresight roll of 0.500 mrad (3 sigma) over 1.0 seconds.	Stability sufficient to minimize PolyCam blur to within 0.5 pixels.	OCAMS, Spacecraft	MRD-61 MRD-504
MRD-441	6.1.2	MapCam			
MRD-442	6.1.2.1	MapCam Pointing Accuracy			
MRD-443		At the beginning of an in-flight observation, the flight system shall point the MapCam boresight at the intended inertial target (Bennu) to within 18.33 mrad (3 sigma) with a boresight roll control of 15.00 mrad (3 sigma).	Alignment of FOV relative to mean target position or target surface feature to within 25% of the width of the field-of-view, 3-sigma, and to within 15 pixels due to the roll around the boresight.	OCAMS, Spacecraft	MRD-576 MRD-583
MRD-595	6.1.2.2	MapCam Pointing Knowledge - Navigation			

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ID	Object Number	PLA-OSIRIS-REx-RQMT-0001, Rev K, Released by CCR-0618, Dated March 11, 2016	Rationale	Subsystem Allocation	Parent ID
MRD-596		After the in-flight calibration data of the spacecraft and science instruments are analyzed, the combined spacecraft and MapCam pointing knowledge shall be within 0.50 mrad (3 sigma) for the boresight and 5.00 mrad (3 sigma) for the boresight roll. This requirement applies to the Orbital B, Reconnaissance, TAG Rehearsal, and Sample Collection phases of the mission.	The pointing knowledge of images used in the building of the shape model contributes to the overall uncertainty in the location of landmarks on the shape and the uncertainty of the orientation of landmarks in inertial space due to spin state errors. At approximately 800m from the surface, a 450 microrad pointing error of MapCam results in about 40cm error in the tracking measurement. If the surface features at this altitude allow a corresponding shape and spin resolution to about the same level, say 50 cm, then the rss tracking uncertainty for each image is about 60 cm. Using this tracking uncertainty in our current navigation scenario in the orbits leading up to TAG results in ~1m orbit uncertainty just before the de-orbit maneuver. These are the values used to derive the orbit covariance matrix that is sampled to begin the TAG Monte Carlo analysis. This is the basis of the TAG error ellipse meeting requirements in the DRM, so this is the rationale for having the 450 microrad pointing error requirement. If this orbit uncertainty grows, then the TAG ellipse on the surface will also get larger. Slightly relaxing the system-level requirement to 500 microrad minimized design impacts on spacecraft and OCAMS to meet their allocations. Relaxed requirement can be accommodated in operations by not using images with unacceptable pointing error in orbit determination solutions. Planned OpNav images already include margin against "bad" images.	OCAMS, Spacecraft	MRD-516
MRD-444	6.1.2.3	MapCam Pointing Knowledge - Science			
MRD-445		After the in-flight calibration data of the spacecraft and science instruments are analyzed, the combined spacecraft and MapCam pointing knowledge shall be known to within 7.33 mrad (3 sigma) for the boresight and 5.00 mrad (3 sigma) for the boresight roll of the intended target (Bennu).	Knowledge of alignment of FOV relative to mean target position or target surface feature to within 10% of the width of the field of view and to within 5 pixels for the boresight roll; observations of star clusters will produce more accurate knowledge capability.	OCAMS, Spacecraft	MRD-144MRD-558MRD-561MRD-576MRD-583
MRD-446	6.1.2.4	MapCam Pointing Short-Term Stability			

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ID	Object Number	PLA-OSIRIS-REx-RQMT-0001, Rev K, Released by CCR-0618, Dated March 11, 2016	Rationale	Subsystem Allocation	Parent ID
MRD-447		During in-flight science observations of an inertial target (Bennu), the flight system shall maintain stable pointing of the MapCam boresight such that it shall not move more than 0.080 mrad (3 sigma) and boresight roll of 0.500 mrad (3 sigma) over 1.0 seconds.	Stability sufficient to minimize MapCam blur within 0.5 pixels.	OCAMS, Spacecraft	MRD-558 MRD-561 MRD-576 MRD-583
MRD-448	6.1.2.5	MapCam Pointing Long-Term Stability			
MRD-449		During in-flight science observations of an inertial target (Bennu), the flight system shall maintain stable pointing of the MapCam boresight such that it shall not move more than 0.080 mrad (3 sigma) and boresight roll of 0.500 mrad (3 sigma) over 10.0 seconds. This requirement applies to the Approach phase.	Stability sufficient to minimize MapCam blur within 0.5 pixels.	OCAMS, Spacecraft	MRD-144
MRD-450	6.1.3	SamCam			
MRD-451	6.1.3.1	SamCam Pointing Accuracy			
MRD-452		At the beginning of an in-flight observation of Bennu, the flight system shall initially point the instrument boresights at their intended targets in inertial space (SamCam boresight) to within 92.25mrad and boresight roll of 15.00 mrad 3 sigma of the intended target (Bennu).	Alignment of FOV Relative to Mean Target Position or Target Surface Features to within 25% of the width of the field-of-view, 3-sigma, and to within 15 pixels due to the roll around the boresight	OCAMS, Spacecraft	MRD-403 MRD-404
MRD-453	6.1.3.2	SamCam Pointing Knowledge			
MRD-454		After the in-flight calibration data of the spacecraft and science instruments are analyzed, the combined spacecraft and SamCam pointing knowledge shall be within 36.65 mrad (3 sigma) for the boresigh and 15.00 mrad (3 sigma) for the boresight roll of the intended target (Bennu)	Knowledge of alignment of FOV Relative to Mean Target Position or Target Surface Features to within 10% of the width of the field of view and to within 15 pixels for the boresight roll	OCAMS, Spacecraft	MRD-403 MRD-404
MRD-455	6.1.3.3	SamCam Pointing Stability			
MRD-456		During in-flight science observations of an inertial target (Bennu), the flight system shall maintain stable pointing of the SamCam boresight such that it shall not move more than 0.870 mrad (3 sigma) with a boresight roll of 5.000 mrad (3 sigma) over 1.0 seconds.	Stability Sufficient to Limit SamCam motion to 1 pixel 1-sigma over 1 second. Actual integration time is closer to 0.1 sec; the boresight roll requirement will guarantee less than of order 0.5 pixel of movement during an exposure.	OCAMS, Spacecraft	MRD-403 MRD-404
MRD-457	6.1.4	OTES			
MRD-458	6.1.4.1	OTES Pointing Accuracy			
MRD-459		At the beginning of an in-flight observation, the flight system shall point the OTES boresight at the intended inertial target (Bennu) to within 4.00 mrad (3 sigma).	We want to be able to target an point on Bennu to within 50% of the OTES FOV.	OTES, Spacecraft	MRD-582 MRD-618
MRD-460	6.1.4.2	OTES Pointing Knowledge			

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MRD-461		After the in-flight calibration data of the spacecraft and science instruments are analyzed, the combined spacecraft and the OTES pointing knowledge shall be within 2.00 mrad (3 sigma) for the boresight of the intended Inertial target (Bennu).	This will provide a post-reconstruction knowledge of where the OTES was pointed on Bennu to within 25% of the OTES FOV.	OTES, Spacecraft	MRD-564MRD-582MRD-618
MRD-462	6.1.4.3	OTES Pointing Stability			
MRD-463		During in-flight science observations of an inertial target (Bennu), the flight system shall maintain stable pointing of the OTES boresight such that it shall not move more than 0.800 mrad (3 sigma) over 2.0 seconds.	We want the control of the spacecraft to be stable to within 25% of the OTES FOV during each 2 sec data acquisition.	OTES, Spacecraft	MRD-564 MRD-582 MRD-618
MRD-464	6.1.5	OLA			
MRD-465	6.1.5.1	OLA Pointing Accuracy			
MRD-466		At the beginning of an in-flight observation, the flight system shall point the OLA boresight at the intended inertial target to within 4.00 mrad.	To ensure that OLA does waste data budget while mapping the surface of Bennu to <0.55m as needed by requirement 2.6.3. Also ensures reasonable overlap with FOV of OVIRS and OTES needed for detailed mapping phase.	OLA, Spacecraft	MRD-166 MRD-567
MRD-467	6.1.5.2	OLA Pointing Knowledge			
MRD-468		After the in-flight calibration data of the spacecraft and science instruments are analyzed, the combined spacecraft and OLA pointing knowledge shall be within 1.90 mrad for the boresight (3 sigma) of the intended target (Bennu), with a boresight roll knowledge of 5.00mrad (3-sigma).	Pointing knowldege of 1.9mrad is needed to ensure that we obtain 1 m horizontal and vertical shape model (L1 Requirement 1.6)	OLA, Spacecraft	MRD-132 MRD-567
MRD-469	6.1.5.3	OLA Pointing Stability			
MRD-470		During in-flight science observations of an inertial target (Bennu), the flight system shall maintain stable pointing of the OLA boresight such that it shall not move more than 0.100 mrad (3 sigma) with a boresight roll of 0.100 mrad (3 sigma) over 1.0 seconds.	Ensures predictable locations and minimal smear of OLA footprints between spacecraft knowledge updates (assumed to be a typical value of 1 Hz)	OLA, Spacecraft	MRD-56 MRD-132 MRD-165 MRD-166 MRD-567
MRD-471	6.1.6	OVIRS			
MRD-472	6.1.6.1	OVIRS Pointing Accuracy			
MRD-473		At the beginning of an in-flight observation, the flight system shall point the OVIRS boresight at the intended inertial target to within 4.00 mrad (3 sigma).	100% of the FOV control.	OVIRS, Spacecraft	MRD-582

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MRD-474	6.1.6.2	OVIRS Pointing Knowledge			
MRD-475		After the in-flight calibration data of the spacecraft and science instruments are analyzed, the combined spacecraft and OVIRS pointing knowledge shall be within 1.00 mrad (3 sigma) of the intended inertial target (Bennu).	This will provide a reconstruction pointing knowledge accuracy of 25% of the OVIRS FOV.	OVIRS, Spacecraft	MRD-562 MRD-582
MRD-476	6.1.6.3	OVIRS Pointing Stability			
MRD-477		During in-flight science observations of an inertial target (Bennu), the flight system shall maintain stable pointing of the OVIRS boresight such that it shall not move more than 0.400 mrad (3 sigma) over 1.0 seconds.	1) Scan rate < 5mrad/sec (nominal 2 mrad/sec); prefer control to 0.1 mrad/sec.	OVIRS, Spacecraft	MRD-562 MRD-582
MRD-478	6.1.7	REXIS			
MRD-479	6.1.7.1	REXIS Pointing Accuracy			
MRD-480		At the beginning of an in-flight observation, the flight system shall point the REXIS boresight at the intended inertial target to within 52.00 mrad with boresight roll control of 10.00 mrad (3 sigma).	This is to achieve maximum surface of the asteroid with the circular FoV of REXIS and to minimize "stray background" from REXIS viewing any sky beyond the limb of Bennu, which will contain bright cosmic X-ray background (CXB) emission as well as (occasionally) bright cosmic X-ray sources.	REXIS, Spacecraft	MRD-197
MRD-481	6.1.7.2	REXIS Pointing Knowledge			
MRD-482		After the in-flight calibration data of the spacecraft and science instruments are analyzed, the combined spacecraft and REXIS pointing knowledge shall be within 1.90 mrad (3 sigma) for the boresight and 7.00 mrad (3 sigma) for the boresight roll of the intended target (Bennu).	In order to minimize coded aperture “imaging factor” (imaging sensitivity vs. mask pixel/detector pixel ratio) and maximize SNR by taking full advantage of 4-1 ratio of mask-to-detector pixel, pointing knowledge should be <1/4 mask pixel (= 1 detector pixel).	REXIS, Spacecraft	MRD-197
MRD-483	6.1.7.3	REXIS Pointing Stability			
MRD-484		During in-flight science observations of an inertial target (Bennu), the flight system shall maintain stable pointing of the REXIS boresight such that it shall not move more than 0.860 mrad (3 sigma) with a boresight roll of 2.300 mrad (3 sigma) over 4.0 seconds.	In order to have an accurate boresight calibration (see alignment calibration), blurring due to attitude jitter should be limited within a half mask pixel.	REXIS, Spacecraft	MRD-197
MRD-499	6.2	Coalignment			

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MRD-663		The table below summarizes the co-alignment requirements in this section and their allocations to the spacecraft and individual science instruments. It is provided here for reference only.			

	Co-Alignment				
	Alignment (mrad) 3 sigma				
Instruments	Req	Instrument Allocation	Instrument Allocation	S/C ref frame Allocation	Systems Margin
PolyCam to MapCam	11.25	PolyCam 2.64	MapCam 5.60	S/C 6.4	21%
MapCam to SamCam	52.36	SamCam 19.80	MapCam 5.60	S/C 10.0	56%
OTES to OVIRS	10.00	OTES 3.30	OVIRS 2.00	S/C 7.4	16%
OTES to PolyCam	10.05	OTES 3.30	PolyCam 2.64	S/C 6.4	23%
OLA to MapCam	17.50	OLA 2.31	MapCam 5.60	S/C 11.4	26%
SamCam to TAGSAM	60.00	SamCam 19.80	TAGSAM 15.00	S/C 17.4	49%
GN&C Lidar to MapCam	17.50	Lidar 10.00	MapCam 5.60	S/C 11.4	8%

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MRD-664		•The Instrument allocation of the co-alignment requirements includes all uncertainties in the relationship between the boresight and the mounting interface. Items in this category include (but are not limited to) thermal variation over temperature, 1 g release, launch shift, and the uncertainty between the boresight and the alignment cube. •The spacecraft allocation of co-alignment requirements includes all uncertainties in the relationship between the two mounting interfaces. Items in this category include (but are not limited to) thermal variation over temperature, 1 g release, launch shift, uncertainty in the ground alignment of instruments, and the resolution in the ability to shim the instruments.			
MRD-487	6.2.1	Co-Alignment: PolyCam to MapCam			
MRD-488		In flight, when mounted to the spacecraft and observing Bennu, the instrument boresight vectors between PolyCam and MapCam shall point in the same direction within 11.25 mrad (0.64 deg) 3 sigma.	Co-alignment is required so that the MapCam can see at least 1/4 of the scene observed by PolyCam.	OCAMS, Spacecraft	MRD-123
MRD-489	6.2.2	Co-Alignment: MapCam to SamCam			
MRD-490		In flight, when mounted to the spacecraft and observing Bennu, the boresight of SamCam, minus the design cant that keeps the TAGSAM Sampler Head within SamCam's FOV at 3m, and the boresight of MapCam shall point in the same direction within 17.45 mrad (1.00 deg) 3 sigma.	This alignment ensures that the MapCam field is contained by SamCam.	OCAMS, Spacecraft	MRD-30
MRD-491	6.2.3	Co-Alignment: OTES to OVIRS			
MRD-492		In flight, when mounted to the spacecraft and observing Bennu, the instrument boresight vectors between OTES and OVIRS shall point in the same direction within 10.00 mrad (0.57 deg) 3 sigma.	OVIRS and OTES spectroscopic data need to be related to each other under similar illumination and emission angles. With the relative pointing error between the OTES and OVIRS limited to 10 mrad, the data will be collected under nearly identical illumination and emission angles (less than 1.2 degrees at 500 m range, the closest distance that OVIRS is required to collect data).	OTES, OVIRS, Spacecraft	MRD-118 MRD-140
MRD-493	6.2.4	Co-Alignment: OTES to PolyCam			
MRD-494		In flight, when mounted to the spacecraft and observing Bennu, the instrument boresight vectors of OTES and PolyCam shall point in the same direction within 10.05mrad (0.58deg) 3 sigma.	This alignment ensures that the OTES field of view is completely contained within the PolyCam field of view. PolyCam provides context for what OTES is seeing during Orbital B spectral mapping.	OTES, OCAMS, Spacecraft	MRD-140 MRD-618
MRD-495	6.2.5	Co-Alignment: OLA to MapCam			
MRD-496		In flight, when mounted to the spacecraft and observing Bennu, the instrument boresight vectors between OLA and MapCam shall point in the same direction within 17.50 mrad (1.00 deg) 3 sigma	This alignment ensures that the MapCam field of view will lie completely within the OLA field of view.	OLA, OCAMS, Spacecraft	MRD-123 MRD-516
MRD-497	6.2.6	Co-Alignment: SamCam to TAGSAM			

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ID	Object Number	PLA-OSIRIS-REx-RQMT-0001, Rev K, Released by CCR-0618, Dated March 11, 2016	Rationale	Subsystem Allocation	Parent ID
MRD-498		The center of the TAGSAM Sampler Head when the arm is extended to the TAG position shall be located within the central 104.72 mrad of the SamCam field of view (3-sigma).	SamCam will observe the sample site during the TAG and contain the TAGSAM within it's FOV.	OCAMS, Spacecraft	MRD-380
MRD-593	6.2.7	Co-Alignment: GN&C LIDAR to MapCam			
MRD-594		In flight, when mounted to the spacecraft and observing Bennu, the instrument boresight vectors between GN&C LIDAR and MapCam shall point in the same direction within 17.50 mrad (1.00 deg) 3 sigma.	This is required for establishing the TAG approach corridor by using MapCam images to calibrate where lidar returns fall on the shape model.	OCAMS, Spacecraft	MRD-13

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Origins, Spectral Interpretation, Resource Identification, and Security–Regolith Explorer (OSIRIS-REx)

PLRA-PMP-NF-OREX
Planetary Missions Program Plan
Program Level Requirements Appendix for the OSIRIS-REx Project

January 2013
with Change 1 (11/9/15)

NASA Headquarters
Washington, DC. 20024-3210

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Reference Documents

1. New Frontiers Announcement of Opportunity (AO) NNH09ZDA007O, dated April 20, 2009
2. OSIRIS-REx Concept Study Report, dated January 28, 2011

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Baseline	January 2013	ALL	
Editorial	November 2015	ALL	Title Page, Header, Updated Governing Program Plan in Scope

Table of Contents

1.0 SCOPE

This appendix to the New Frontiers Program Plan identifies the science, mission, schedule, and cost requirements imposed on the Origins, Spectral Interpretation, Resource Identification, and Security–Regolith Explorer (OSIRIS-REx) Project for the development and operation of the Mission under the New Frontiers Program. Requirements begin in Section 4. Sections 1, 2, and 3 are intended to set the context for the requirements that follow.

General requirements applicable to all New Frontiers Missions are found in the main body of the New Frontiers Program Plan, NFWR-PLAN-001, of which this document is an appendix thereof.

This document serves as the basis for mission assessments conducted by NASA during the development period and provides the baseline for the determination of the science mission success during the operational phase.

Program authority is delegated from the National Aeronautics and Space Administration (NASA) Associate Administrator for the Science Mission Directorate (AA/SMD) through the SMD Planetary Science Division to the New Frontiers Program Manager at the Marshall Space Flight Center (MSFC) to the Principal Investigator (PI), Dr. Dante Lauretta. The PI is responsible for the overall success of the OSIRIS-REx Mission and is accountable to the AA/SMD for the scientific success and to the New Frontiers Program Manager for its programmatic success. The PI will also coordinate the work of the co-investigators and has ultimate responsibility for the OSIRIS-REx outreach efforts.

The PI delegates the technical implementation to the Project Manager (PM). The PM is responsible for design, development, test, and mission operations and shall coordinate the work of all OSIRIS-REx partners and contractors.

The NASA Agency Program Management Council (PMC) is the governing PMC for the OSIRIS-REx Mission. The Goddard Space Flight Center (GSFC) Director-of is responsible for certifying OSIRIS-REx Mission readiness to the AA/SMD. The New Frontiers Program Office will participate in the Mission Readiness Review, and Mission Directorate and Agency PMCs, and independently certifies mission readiness.

Changes to information and requirements contained in this document require approval by the Associate Administrator for the Science Mission Directorate, the PI, the GSFC Director-of, and the New Frontiers Program Manager.

This project is part of the New Frontiers Program which is governed by the Planetary Missions Program Plan. Any extended missions will be captured as an addendum to this PLRA.

2.0 SCIENCE DEFINITION

The OSIRIS-REx mission will return the first pristine samples of carbonaceous material from the surface of a primitive asteroid. OSIRIS-REx's target asteroid is (101955) 1999 RQ36 (hereafter RQ36). RQ36 and all asteroids are remnants of the original building blocks of the terrestrial planets. Knowledge of their chemical and physical nature, distribution, formation, and evolution is fundamental to understanding planet formation and the origin of life. Only by understanding the organic chemistry and geochemistry of an asteroid sample can this knowledge be acquired.

Planned for launch in September 2016, OSIRIS-REx will return a minimum of 60 g of pristine bulk regolith and a separate 26 cm^2 of fine grained surface material from RQ36. Analyses of these samples will provide unprecedented knowledge about presolar history through the initial stages of planet formation to the origin of life. Prior to sample acquisition, OSIRIS-REx performs global mapping of the texture, mineralogy, and chemistry of RQ36, resolving geological features, revealing its geologic and dynamic history, and providing context for the returned samples and an identification of potential resources. The instruments also document the regolith at the sampling site *in situ* at scales down to the sub-centimeter. OSIRIS-REx also studies the Yarkovsky effect, a non-Keplerian force affecting the orbit of this potentially hazardous asteroid, and provides the first ground truth for telescopic observations of carbonaceous asteroids. RQ36 has a significant probability of impacting the Earth (>1:2000 in the late 22nd Century).

2.1 Science Objectives for OSIRIS-REx

OSIRIS-REx has five science objectives that are directly traceable to five major questions outlined in the NASA Solar System Exploration Roadmap (SSER) and four key questions in the National Research Council (NRC) New Frontiers in the Solar System (NFSS) document. The five scientific objectives of the OSIRIS-REx asteroid sample return mission are:

- Return and analyze a sample of pristine carbonaceous asteroid regolith in an amount sufficient to study the nature, history, and distribution of its constituent minerals and organic material.
- Map the global properties, chemistry, and mineralogy of a primitive carbonaceous asteroid to characterize its geologic and dynamic history and provide context for the returned samples.
- Document the texture, morphology, geochemistry, and spectral properties of the regolith at the sampling site *in situ* at scales down to the sub-centimeter.
- Measure the Yarkovsky effect on a potentially hazardous asteroid and constrain the asteroid properties that contribute to this effect.
- Characterize the integrated global properties of a primitive carbonaceous asteroid to allow for direct comparison with ground-based telescopic data of the entire asteroid population.

3.0 PROJECT DEFINITION

3.1 Project Organization and Management

The OSIRIS-REx Project organization chart is shown in Figure 1. The PI, Dr. Dante Lauretta, of the University of Arizona's (UA) Lunar and Planetary Laboratory (LPL), is responsible to NASA for meeting the scientific objectives of the OSIRIS-REx mission within cost and schedule. The OSIRIS-REx core team consists of UA, GSFC, and Lockheed Martin (LM). The PI, Deputy PI (DPI), Project Planning and Control Officer, and Mission Instrument Scientist are from UA. UA also provides the Science Team management, Science Processing and Operations Center (SPOC), the Education and Public Outreach (E/PO) functions, and the integrated OSIRIS-REx Camera Suite (OCAMS).

The PM and Deputy PM (DPM) are located at GSFC, which provides the Project Scientist (PS), Deputy Project Scientist (DPS), Project System Engineer, Chief Safety and Mission Assurance Officer, Instrument System Manager, Ground Segment Manager, Flight System Manager, Flight Dynamics Lead, and Launch Segment Manager. GSFC is also responsible for the development of the OSIRIS-REx Visible Infrared Spectrometer (OVIRS) instrument and oversight of the OSIRIS-REx Camera Suite (OCAMS), OSIRIS-REx Thermal Emission Spectrometer (OTES), OSIRIS-REx Laser Altimeter (OLA), and Regolith X-ray Imaging Spectrometer (REXIS) instruments.

LM is responsible for providing the OSIRIS-REx spacecraft, the Touch-and-Go Sample Acquisition Mechanism (TAGSAM), and the Sample Return Capsule (SRC). LM also provides the Flight Systems Manager (FSM), the Mission System Integration and Test (MSIT) Team, mission operations, and SRC recovery.

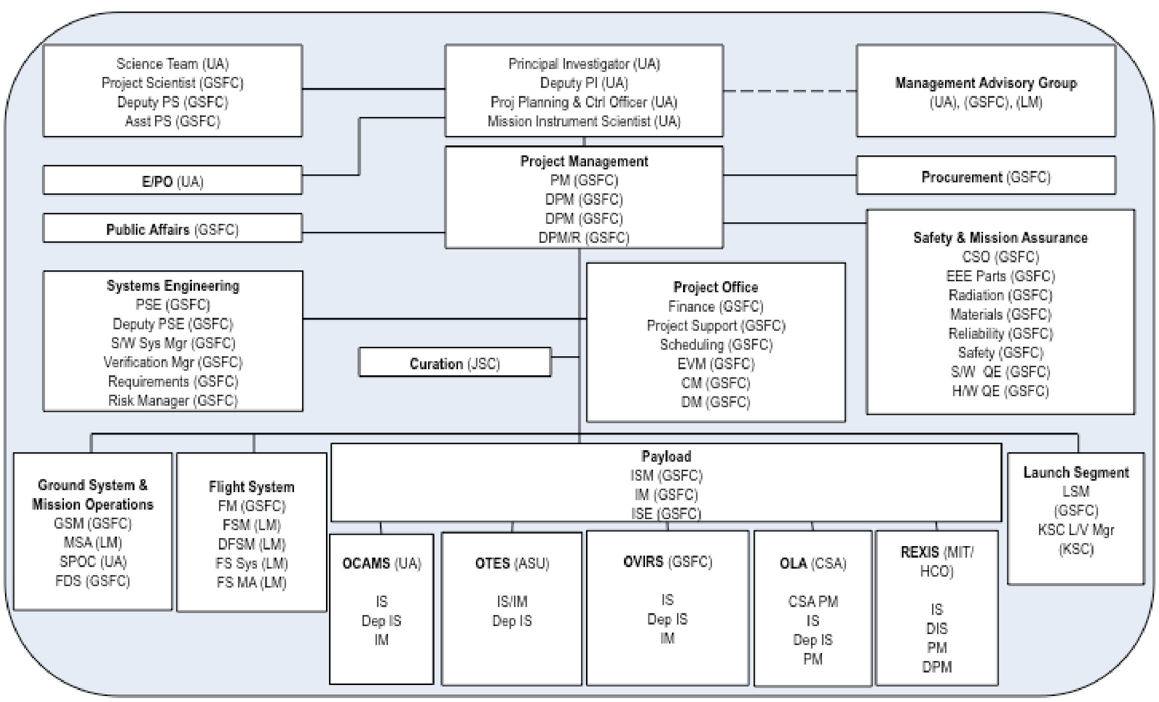

Figure 1. OSIRIS-REx Project Organization Chart

3.2 Project Acquisition Strategy

Figure 2 depicts the financial and contractual interfaces and arrangements, as well as the funding paths for each.

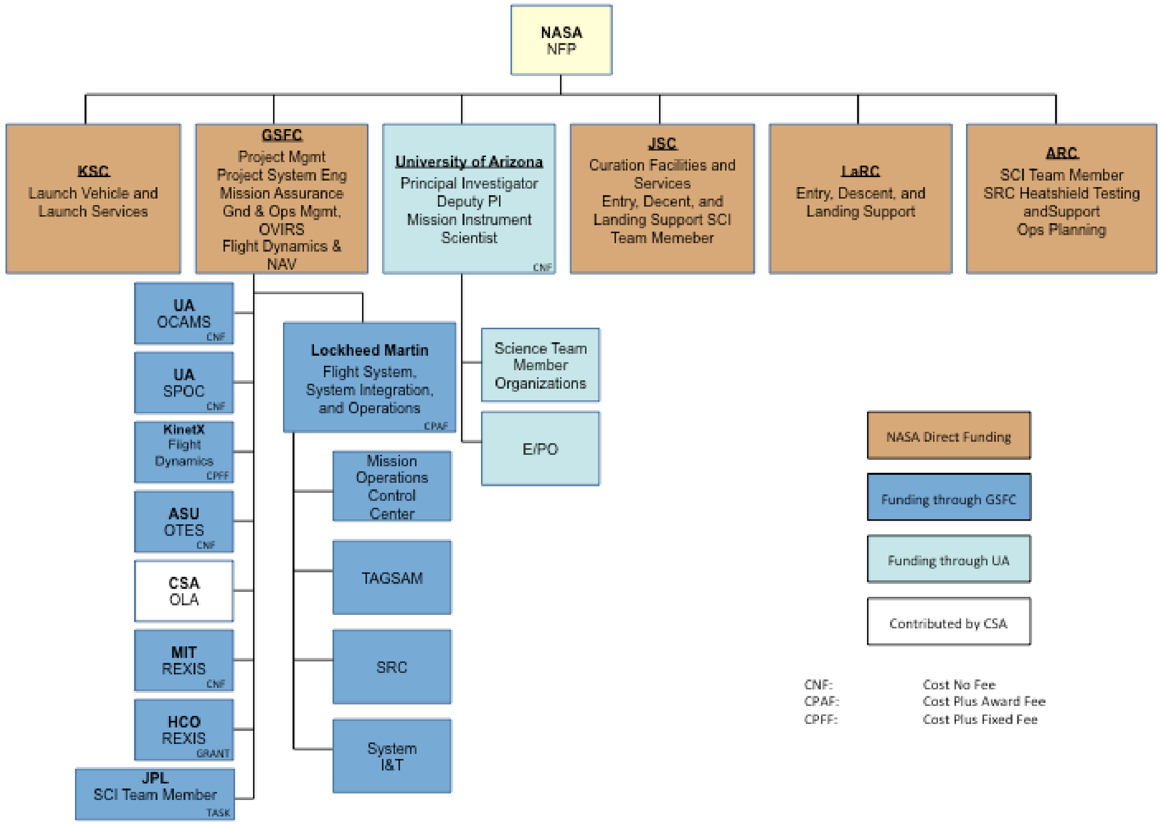

Figure 2. OSIRIS-REx Acquisition Strategy

4.0 PROGRAMMATIC REQUIREMENTS

4.1 Science Requirements

4.1.1. Baseline Science Requirements

The OSIRIS-REx Mission will achieve the science objectives of Section 2.1 by meeting the following requirements. The OSIRIS-REx Project shall:

4.1.1.1 Return ≥60 g of pristine bulk sample from RQ36. No more than 25% of the total returned mass will be used by the mission team to meet its science objectives. 'Pristine' is defined to mean that no foreign material introduced into the sample hampers the scientific analysis of the sample defined in 4.1.1.5.

Rationale: Returning a sample is the fundamental goal of OSIRIS-REx. 15 g of sample material is sufficient to conduct analyses required for requirement 4.1.1.5. A total of ≥45 g (≥75% of the sample) will be available to NASA to meet the policy requirement to archive samples for future analysis.

4.1.1.2 Document the contamination of the sample acquired from collection, transport, curation, and distribution.

Rationale: Documentation of contamination will improve the understanding of the sample analysis and allow the determination of true sample signals above the noise of contamination.

4.1.1.3 Contact ≥26 cm^2 of surface material from RQ36 and return the TAGSAM contact surface. No more than 25% of the contact surface will be used by the mission team to meet its science objectives.

Rationale: The contact sample provides a backup collection mechanism. Surface sample allows analysis of space-weathered mineralogy and the source of surface spectral properties. 6.5 cm^2 of surface material is sufficient to conduct analyses required for requirement 4.1.1.5. A total of 19.5 cm^2 (75%) will be available to NASA to meet the policy requirement to archive samples for future analysis.

4.1.1.4 For the sample site, document the texture to sub-cm resolution and the morphology, geochemistry, and spectral properties sufficiently to select the site and provide context for the sample. 'Resolution' is defined as the root-mean-square spot size characterizing the sub-cm imager.

Rationale: Proper context of the sample will increase the value of the science.

4.1.1.5a Produce a sample catalog within 6 months of return.

Rationale: 6 months is sufficient to catalog the returned sample with enough detail to allow the broader scientific community to intelligently request samples for analysis.

4.1.1.5b Analyze the returned sample to determine the presolar history, formation age, nebular and parent-body alteration history, relation to

known meteorites, organic history, space weathering, resurfacing history, and energy balance in the regolith of RQ36.

Rationale: These measurements are the ultimate objectives of OSIRIS-REx.

4.1.1.6 Produce a shape model of RQ36 with 1-m lateral and vertical resolution.

Rationale: The shape model is necessary to obtain the sample, and it is important for improved understanding of the geology of RQ36 in particular, and asteroids in general.

4.1.1.7 Determine the surface slopes, accelerations and geopotential of RQ36 at 1-m spatial resolution.

Rationale: These parameters are necessary to obtain the sample, and they are useful for understanding the surface properties of RQ36 in particular and asteroids in general.

4.1.1.8 Determine the bulk density of RQ36 to within 1%, determine up to the fourth degree and order gravity harmonic coefficients, and search for and characterize any density inhomogeneities within the asteroid.

Rationale: These parameters are necessary to obtain the sample, and they are important for determining the physical properties and internal structure of RQ36.

4.1.1.9 Measure the number, sizes, spatial distribution, and morphologies of possible craters and boulders, regolith distributions, and search for evidence of surface expression of internal structure on RQ36.

Rationale: These parameters will aid in site selection, and they provide better understanding of RQ36's geologic and dynamic history.

4.1.1.10 Resolve key mineralogical and organic features with spectral absorptions $\geq$5% to detect the following species: adsorbed water, phyllosilicates, carbonates, sulfates, silicates, oxides, and hydrocarbons, as well as determine mineral, organic, and phase abundances on the surface of RQ36, at a global spatial resolution of 50 m or better.

Rationale: Spectral maps of the surface of RQ36 aid in the selection of a scientifically interesting sample site and provide significant information on the compositional diversity across the entire asteroid. 50 m is sample site size.

4.1.1.11 Search for and spectrally and visually characterize any regions of active volatile outgassing from the surface of RQ36.

Rationale: This is necessary for the protection of the spacecraft and the selection of interesting sample sites.

4.1.1.12 Search for and spectrally and visually characterize any satellites in orbit around RQ36.

Rationale: This is necessary for the protection of the spacecraft, and discovery of a satellite would provide constraints on the dynamical history of RQ36.

4.1.1.13 Search for and characterize the effects of space weathering on RQ36.

Rationale: These data aid the identification of fresh material available for sampling. They also provide historical information on RQ36 and a data point for space weathering of carbonaceous asteroids.

4.1.1.14 Constrain the properties of RQ36 that contribute to the Yarkovsky effect and measure the magnitude of the Yarkovsky effect.

Rationale: The Yarkovsky effect is the major source of uncertainty in long-term prediction of asteroid orbits. Understanding this effect is critical to predicting future collisions of asteroids with the Earth.

4.1.1.15 Measure the astrometric, photometric, and spectroscopic properties of RQ36.

Rationale: These measurements provide the link between Earth-based and space-based telescopic observations of asteroids and the actual surface properties.

4.1.2 Threshold Science Requirements

4.1.2.1 Return ≥60 g of bulk sample from RQ36. No more than 25% of the total returned mass will be used by the mission team to meet its science objectives

Rationale: Threshold wording removes the “pristine” aspect of the requirement. Returning a sample, even if it is contaminated, is still extremely valuable to the science community. This is the primary objective of OSIRIS-REx.

4.1.2.2 **Same as baseline:** Document the contamination of the sample acquired from collection, transport, curation, and distribution.

Rationale: It is critical to understand exactly what contaminants are present, so contamination is not confused with species native to the asteroid sample.

4.1.2.3 **Same as baseline:** Contact ≥26 cm^2 of surface material from RQ36, return the TAGSAM contact surface. No more than 25% of the contact surface will be used by the mission team to meet its science objectives.

Rationale: The contact sample provides a backup collection mechanism. Surface sample allows analysis of space weathered mineralogy and the source of surface spectral properties. 6.5 cm^2 of surface material is sufficient to conduct analyses required for requirement 4.1.1.5. A total of 19.5 cm^2 (75%) will be available to NASA to meet the policy requirement to archive samples for future analysis.

4.1.2.4 For the sample site, document the texture and morphology to sub-cm resolution. ‘Resolution’ is defined as the root-mean-square spot size characterizing the sub-cm imager.

Rationale: This is necessary for sample site selection and understanding the grain-size distribution at the sample site.

4.1.2.5a **Same as baseline:** Produce a sample catalog within 6 months of return.

Rationale: 6 months is sufficient to catalog the returned sample with enough detail to allow the broader scientific community to intelligently request samples for analysis.

4.1.2.5b **Same as baseline:** Analyze the returned sample to determine the presolar history, formation age, nebular and parent-body alteration history, relation to known meteorites, organic history, space weathering, resurfacing history, and energy balance in the regolith of RQ36.

Rationale: These measurements are the ultimate objectives of OSIRIS-REx.

4.1.2.6 **Same as baseline:** Produce a shape model of RQ36 with 1-m lateral and vertical resolution.

Rationale: This is necessary to safely sample the asteroid.

4.1.2.7 **Same as baseline:** Determine the surface slopes, accelerations and geopotential of RQ36 at 1-m spatial resolution.

Rationale: This is necessary to safely sample the asteroid.

4.1.2.8 **Same as baseline:** Determine the bulk density of RQ36 to within 1%, determine up to the fourth degree and order gravity harmonic coefficients, and search for and characterize any density inhomogeneities within the asteroid.

Rationale: This is necessary to safely sample the asteroid.

4.1.2.9 Measure the spatial distribution of regolith on RQ36.

Rationale: This is necessary to select a sample site with sufficient regolith.

4.1.2.10 Fully descoped for threshold mission.

4.1.2.11 Search for and visually characterize any regions of active volatile outgassing from the surface of RQ36.

Rationale: This is necessary for the safety of the spacecraft.

4.1.2.12 Search for and determine the orbits of any satellites in orbit around RQ36.

Rationale: This is necessary for the safety of the spacecraft.

4.1.2.13 Fully descoped for threshold mission.

4.1.2.14 Measure the magnitude of the Yarkovsky effect.

Rationale: This enables better understanding of the risk of RQ36 to Earth.

4.1.2.15 Fully descoped for threshold mission.

4.1.3 Science Implementation Requirements

The OSIRIS-REx Mission science objectives are achieved through an instrument suite based on four previously flown science instruments, a radio science capability, and the

sample acquisition mechanism and sample return capsule. This equipment operates in concert with ground-based modeling efforts to refine knowledge of RQ36 at each phase of the mission, culminating in detailed documentation of the sample site. All measurement requirements are well within existing capabilities. A description of each of the science instruments is provided in Table 1.

Table 1: Science Implementation Equipment

Equip	Description	Science Investigation	Associated Baseline Requirements	Contributes to these Threshold Requirements[1]
OCAMS PolyCam	Ritchey-Chretien telescope	Provides long-range RQ36 acquisition and sub-cm imaging of the surface of RQ36	4.1.1.4, 4.1.1.6, 4.1.1.7, 4.1.1.8, 4.1.1.9, 4.1.1.11, 4.1.1.12, 4.1.1.13, 4.1.1.14, 4.1.1.15	4.1.2.4, 4.1.2.6, 4.1.2.7, 4.1.2.8, 4.1.2.9, 4.1.2.11, 4.1.2.14
OCAMS MapCam	Modified double-Gauss refractor	Supports optical navigation during proximity-operations, global mapping, and sample-site reconnaissance	4.1.1.4, 4.1.1.6, 4.1.1.7, 4.1.1.8, 4.1.1.9, 4.1.1.10, 4.1.1.11, 4.1.1.12, 4.1.1.13, 4.1.1.14, 4.1.1.15	4.1.2.4, 4.1.2.6, 4.1.2.7, 4.1.2.8, 4.1.2.9, 4.1.2.11, 4.1.2.14
OCAMS SamCam	F/11 modified Cooke triplet refractor	Performs sample-site characterization and sample-acquisition documentation	4.1.1.4	4.1.2.4
OLA	Scanning-Light Detection and Ranging (LIDAR) instrument	Laser altimeter for precise ranging, topography, and shape model development	4.1.1.4, 4.1.1.6, 4.1.1.7, 4.1.1.8, 4.1.1.9, 4.1.1.14	4.1.2.4, 4.1.2.6, 4.1.2.7, 4.1.2.8, 4.1.2.9, 4.1.2.14

[1] Instruments contribute to these threshold requirements, but are not necessarily required to meet them. Any two out of three OCAMS cameras, TAGSAM, and radio science are the only items necessary to meet all threshold requirements.

OVIRS	Point spectrometer with a 4-mrad field of view (FOV) that provides spectra from 0.4–4.3 μm.	Visible and near IR spectrometer (0.4 – 4.3 μm) to map minerals and organics	4.1.1.4, 4.1.1.10, 4.1.1.11, 4.1.1.12, 4.1.1.13, 4.1.1.14, 4.1.1.15	N/A
OTES	Fourier-transform-interferometer point spectrometer that collects hyper-spectral thermal infrared data over the spectral range from 4 to 50 μm (2500–200 cm^{-1}) with a spectral resolution of 10 cm^{-1} and an 8-mrad FOV.	Thermal IR spectrometer (4–50 μm) to map minerals and thermal properties	4.1.1.4, 4.1.1.10, 4.1.1.11, 4.1.1.12, 4.1.1.13, 4.1.1.14, 4.1.1.15	N/A
REXIS	Coded aperture soft X-ray (0.3–7.5 keV) telescope. REXIS is a student collaboration experiment (SCE).	Complement onboard mineral mapping by adding spatially resolved elemental abundance mapping achieved through X-ray spectrometry	4.1.1.10, 4.1.1.11, 4.1.1.15[2], 8.1	N/A
TAGSAM	Touch-and-Go Sample Acquisition Mechanism consisting of two major components, a sampler head and an articulated positioning arm.	Touch-and-go sampling system "kisses" the surface and returns >60 g of regolith plus a surface sample	4.1.1.1, 4.1.1.2, 4.1.1.3	4.1.2.1, 4.1.2.2, 4.1.2.3
Radio Science	Spacecraft navigation and ancillary data	Total mass and gravity field coefficients	4.1.1.7, 4.1.1.8, 4.1.1.14	4.1.2.7, 4.1.2.8, 4.1.2.14

4.2 Mission Performance

4.2.1 The OSIRIS-REx mission shall be Category I per NASA Procedural Requirement (NPR) 7120.5E, NASA Space Flight Program and Project Management Requirement.

4.2.2 The OSIRIS-REx Mission shall be risk Classification B per NPR 8705.4, Risk Classification for NASA Payloads. OTES and OVIRS, since they are not required to meet threshold requirements, may be changed to risk

[2] REXIS enhances these three requirements beyond the baseline. The instrument is not required to meet baseline.

Classification C with program approval. The REXIS student experiment is class D.

For the OLA instrument, the Canadian Space Agency (CSA) will apply their quality assurance policies and procedures. OLA quality assurance plans will be described in the Joint Project Implementation Plan (JPIP). NASA will not assess the OLA payload class under NPR 8705.4.

4.2.3 The OSIRIS-REx Mission shall launch in the window that opens in September, 2016. A back-up window is available approximately one year later, but costs are based on achieving the 2016 window.

4.2.4 The OSIRIS-REx Mission shall return a sample of RQ36 to Earth no later than September, 2023.

4.2.5 The OSIRIS-REx Mission shall perform a divert maneuver after release of the SRC so that the spacecraft will not re-intercept Earth, Moon, or any solar system body restricted by Planetary Protection.

4.2.6 The nominal end of the OSIRIS-REx Mission operations shall be October, 2023 (sample return capsule recovery +30 days).

4.2.7 The OSIRIS-REx project curation and sample analysis period shall be complete by September 30, 2025.

4.3 Mission Success Criteria

For mission success, the following criteria must be met:

4.3.1 Rendezvous with asteroid 1999 RQ36

4.3.2 Contact the asteroid surface with TAGSAM and collect a sample

4.3.3 Safely return asteroid sample to Earth and deliver them to the curatorial facility at the NASA Johnson Space Center

4.3.4 Provide for the initial analysis and plan for the long-term curation of the returned sample

4.3.5 Ensure a sample allocation process is in place to conduct early science return studies as well as long-term general studies

4.4 Spacecraft Performance

The spacecraft shall provide the required subsystem support in attitude control, propulsion, power, thermal control, telecommunications, command and data handling, and other systems to satisfy the science and instrument requirements of section 4.1, for the duration of the nominal mission.

4.5 Launch Requirements

Launch Services Program (LSP) is responsible for launch vehicle procurement. LSP is responsible for ensuring that the launch vehicle is ready to support OSIRIS-REx launch at the beginning of its window. LSP is responsible for launch vehicle procurement and readiness within the budget provided through the Planning, Programming, Budgeting,

and Execution (PPBE) process. OSIRIS-REx will be launched on an expendable launch vehicle of Risk Category 3, per NASA Policy Directive (NPD) 8610.7D. Launch Services Risk Mitigation Policy for NASA-owned and/or NASA-sponsored payload/missions.

4.5.1 OSIRIS-REx shall use launch vehicle environments agreed-to by LSP.

4.6 Mission Data Requirements

4.6.1 Science Data Management

The OSIRIS-REx PI shall be responsible for initial analysis of the scientific data, its subsequent delivery to an appropriate data repository, the publication of scientific findings, and communication of results to the public. Additionally, the OSIRIS-REx PI shall be responsible for collecting engineering and ancillary information necessary to validate and calibrate the scientific data prior to depositing it in a NASA approved data repository. The data acquired to characterize RQ36 will be delivered on a timeline determined in coordination with the Planetary Data System (PDS) Small Bodies Node. The OSIRIS-REx science data base shall be made available to the science community without restrictions or proprietary data rights of any kind.

4.6.2 Data Management Plan

The OSIRIS-REx Project shall develop a data management plan to address the total activity associated with the flow of science data, from acquisition, through processing, data product generation and validation, to archiving and preservation. The data management plan shall be formally approved as a Project-Level document no later than the Project's Critical Design Review. Science analysis software development, utilization, and ownership shall be covered in the Data Management Plan.

4.6.3 Final Mission Reports

The OSIRIS-REx Project shall provide final mission reports to the New Frontiers Program. The reports are due to the program prior to the termination of the project at the end of the data analysis period. Each report is described below.

<u>Mission Success Report</u>

A Mission Success Report shall be provided to the OSIRIS-REx Program Scientist summarizing the scientific accomplishments of the mission and an assessment of how these accomplishments fulfill the baseline or threshold requirements in section 4.1 and 4.2, respectively.

<u>Mission Lessons Learned Report</u>

A Mission Lessons Learned Report shall be provided to the New Frontiers Program Office summarizing the technical performance of the spacecraft, science instruments, and project, and any lessons learned, through all phases of the project's life cycle.

4.7 Curation Requirements

The OSIRIS-REx asteroid samples will be recovered at the Utah Test and Training Range (UTTR) and then housed in a secure cleanroom facility at the NASA Johnson Space Center (JSC). The curation staff at JSC will be involved with both the Utah recovery and later sample storage and curation. Curation requirements for the OSIRIS-REx Mission are provided below.

4.7.1 The OSIRIS-REx Project shall be responsible for development and implementation of detailed contamination control plans necessary to understand the contamination history of the returned sample. This plan must cover: assembly, test, and launch of the Sample Acquisition and Return Assembly (SARA), TAGSAM, and SRC (including the sample canister); recovery and transport of the SRC at UTTR; the curation facility at JSC; contamination witness plates; known potential contaminants including propellant; and any other space-exposed hardware returned to Earth.

4.7.2 The OSIRIS-REx Project shall have capability to store the SRC under controlled conditions, to establish a safe purge in the cleanroom at UTTR during processing of the SRC, and preparation for and transfer to JSC after recovery.

4.7.3 The OSIRIS-REx samples and witness material shall be stored and processed in a secure cleanroom facility at JSC.

4.7.4 The OSIRIS-REx Project shall analyze the SRC for assessment of contamination and capsule performance.

4.8 Schedule Requirements

The OSIRIS-REx Project's Integrated Master Schedule will be developed around a set of major milestones. These milestone requirements are provided below.

4.8.1 The OSIRIS-REx Project shall plan to the following Life Cycle Reviews:

a. Preliminary Design Review (PDR) to be completed by the 2nd quarter of FY13.
b. Critical Design Review (CDR) to be completed by the 3rd quarter of FY14.
c. Systems Integration Review (SIR) to be completed by 2nd quarter of FY15.
d. Operational Readiness Review (ORR) to be completed by 3rd quarter FY16.

Other milestones (launch, sample return, end of mission operations, and completion of sample analysis) are discussed in Section 4.2/Mission Performance.

NASA MISSION COST REQUIREMENTS

5.1 Cost Cap

The OSIRIS-REx cost cap is $1051.4M Real-Year (RY) $ for the design, development and operation of the mission. The OSIRIS-REx cost cap includes launch vehicle service costs of $240.9M (RY$) but excludes external contributions. The corresponding funding profile, based on this cost cap, for OSIRIS-REx is provided in Table 2. This table reflects the funding profile as determined at confirmation, including the $3.9M reduction for STEM Education. Updates to this profile will not be tracked through this document.

Table 2: OSIRIS-REx Budget Profile by Fiscal Year

BUDGET PROFILE BY FISCAL YEAR										
	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	BTC	TOTAL LCC
TOTAL ($M)	2.4	5.8	99.8	129.4	218.7	234.1	179.4	30.9	150.9	1,051.4

5.1.1 The OSIRIS-REx PI-managed cost shall not exceed $803.1M (RY$). This PI-managed cost cap does not include launch services, external contributions, or the REXIS student experiment.

5.1.2 The REXIS student experiment costs shall not exceed $7.4M (RY$).

5.2 Seventy Percent Confidence Level Reserves

Consistent with NASA requirements NPR 1000.5 Policy for NASA Acquisitions, Projects are to be baselined or rebaselined and budgeted at a confidence level of 70 percent or the level approved by the decision authority of the Agency Program Management Council (APMC). The 70 percent confidence level is the point on the joint cost and schedule probability distribution where there is a 70 percent probability that the project will be completed at or lower than the estimated amount and at or before the projected schedule. The basis for a confidence level less than 70 percent is to be formally documented. A continuation review shall be required before granting an increase to the cost cap.

5.2.1 The OSIRIS-REx Project shall develop joint cost and schedule confidence levels for the life cycle cost and schedule associated with the initial lifecycle baseline at Key Decision Point (KDP)-C. Updates will be made as required.

5.3 Cost Management and Scope Reduction

Provided that Program Level Requirements are preserved, and that due consideration has been given to the use of budgeted contingency and planned schedule contingency, the OSIRIS-REx project shall pursue scope reduction and risk management as a means to control cost and schedule. The Project Plan shall include potential scope reductions and the time frame in which they could be implemented. If other methods of cost containment are not practical, the reductions identified in the Project Plan may be exercised; however, any reduction in scientific capability, including those reductions specifically identified in the Project Plan, shall be implemented only after consultation with and approval by the Program Scientist. Any potential scope reductions affecting these Program Requirements shall be agreed to by the signers of this document.

6.0 MULTI-MISSION NASA FACILITIES

Multi-mission NASA facilities required by the OSIRIS-REx Mission include launch services and launch site payload processing facilities at Kennedy Space Center (KSC); the Deep Space Network (DSN); arcjet testing at Ames Research Center (ARC) ; and the Toxicology Lab and Curation Facility at Johnson Space Center (JSC).

7.0 EXTERNAL AGREEMENTS

External agreements for the OSIRIS-REx Mission are provided in Table 3.

Table 3. OSIRIS-REx External Agreements

External Entity	Providing	Affected Baseline Requirement(s)	Affected Threshold Requirement(s)
CSA	OLA Instrument, Co-investigators	4.1.1.4, 4.1.1.6, 4.1.1.7, 4.1.1.8, 4.1.1.9, 4.1.1.14	4.1.2.4, 4.1.2.6, 4.1.2.7, 4.1.2.8, 4.1.2.9, 4.1.2.14[3]
Centre National d'Etudes Spatiales (CNES)	Co-investigators	4.1.1.4, 4.1.1.5, 4.1.1.7, 4.1.1.9, 4.1.1.10, 4.1.1.12, 4.1.1.14, 4.1.1.15	4.1.2.4, 4.1.2.5, 4.1.2.7, 4.1.2.9, 4.1.2.12
US Air Force	Utah Test and Training Range (UTTR)	4.1.1.1, 4.1.1.2, 4.1.1.3	4.1.2.1, 4.1.2.2, 4.1.2.3

The CSA will provide the OSIRIS-REx OLA instrument and co-investigator support at a no-exchange-of-funds basis to the OSIRIS-REx project, in exchange for 4% of the returned sample as specified in the Implementing Arrangement. The OLA contribution is subject to the International Traffic in Arms Regulations (ITAR), administered by the Departments of Commerce and State. A formal Implementation Arrangement between NASA/Headquarters and CSA defining the roles and responsibilities of the parties will be required prior to exports. Besides the Implementation Arrangement between NASA and CSA, the Joint Project Implementation Plan (JPIP), Technical Assistance Agreements (TAAs), and Interface Control Documents (ICDs) are required between performing organizations.

The French Space Agency, Centre National d'Etudes Spatiales (CNES), will provide pre-launch observation and analysis of RQ36, analysis of instrument remote sensing data post-launch, and sample analysis per the Implementing Agreement (IA).

The UTTR will provide personnel and equipment to implement SRC recovery operations and delivery of the sample to the science team.

[3] These requirements can still be met without OLA.

8.0 PUBLIC OUTREACH AND EDUCATION

The OSIRIS-REx Mission shall develop and execute a public outreach, education, and teaching program consistent with the policies and guidelines for education and public outreach described in the New Frontiers Announcement of Opportunity (AO NNH09ZDA007O).

8.1 OSIRIS-REx shall support a student collaboration experiment, known as REXIS, that shall directly engage students at the undergraduate and graduate levels in the conception, design, implementation, and operation of space flight instrumentation for the mission.

9.0 SPECIAL INDEPENDENT EVALUATION

Ordinary independent reviews, such as a Confirmation Review, are required by existing directives and do not constitute special independent evaluation. There are no special independent evaluations required by the New Frontiers Program. However, the governing and/or technical authorities may convene special reviews as they determine necessary per NPR 7120.5E section 2.2.9.

10.0 TAILORING

A preliminary list of deviations/waivers for the OSIRIS-REx project with respect to NPR 7120.5E is provided in Table 4. All deviations/waivers must be provided to the New Frontiers Program Manager, the GSFC Director-of, the Technical Authorities, and the governing DPMC for approval prior to the Confirmation Review (CR)/KDP-C per section 3.6 of NPR 7120.5E.

Table 4. OSIRIS-REx Deviations/Waivers to NPR 7120.5E

Title	Description	NPR 7120.5E Requirement	Justification
None			